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44722	On behalf of the Akaroa Fishermans Association we present our submission to the CCC on the proposed new wharf. Firstly we fully support the reconstruction of the Drummons Wharf as an interim facility to accommodate our needs during the new wharf rebuild (berthage, fuel, loading, crane, etc). We are having on-going discussions with Mr Paul Devlin and Miss Kristine Bouw as to new wharf rebuild (material, width, length, power, fuel, crane, sewage, etc). At this stage we feel a lot to be decided. We are not in favour of the so-called knuckle this would attract people to an area where vehicles, passengers to the carter boats are passing through. It would be a health and safety issue and unnecessary as access to the beach and water front is virtually everywhere in the inner Akaroa Harbour. We would like to be able to speak to the Community Board at the next Akaroa meeting.	J G	Wright	Akaroa	Akaroa Fishermans Association
44721	The new Akaroa Wharf has to have a solid timber decking. Any other material will not fit in with the environment of the hills and the whole atmosphere of the area. As many historical pieces from the old wharf have to be saved and incorporated into the new wharf. At the public display last year an Option 2 was mentioned as a fully concrete deck. This may work at the New Brighton Pier where this view is to the horizon. This will not work in Akaroa for the above reasons and also including its history.	Stephen	Carswell	Akaroa	
44716	Dear Project Team, We write to provide a community business perspective on the wharf redevelopment, in particular the proposed supply of petrol on the wharf for commercial use. We have owned the NPD, Akaroa Motor Garage, in Akaroa for almost 3 years. We are strong supporters of the community and wherever possible like to operate in a way that is mutually beneficial for our community as well as our business. It is simply not possible to achieve one without the other in a community this size. We see this wharf as an exciting opportunity for Akaroa to continue to provide the world class experiences we are known for, while also offering world class infrastructure for a wide range of stakeholders to enjoy. However, we feel the supply of petrol on the wharf is unnecessary; there is a safe and accessible current supply in the town (no market failure), the increased traffic on the wharf that it may attract would present considerable health and safety and environmental risks, and should the use be extended to recreational use	Nina	Wright	Akaroa	Akaroa Motor Garage

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	the impact on the NPD business, and its ability to sustain the current level of service and employment may be compromised. Below I have detailed what we believe to be the three key areas for concern which would not only impact us as a business but the overall enjoyment of the facility for all. *Environmental risk. Does the need justify the risk?* This has to be of very high concern for the Christchurch City Council. The proposal states “Continuing to provide diesel for commercial operators while exploring the possibility of also providing access to petrol for them.” The User Requirements document by Envisor states that there are only three commercial operators who require petroleum supply on the wharf. Two of these are seasonal tourism operators and one is a commercial fishing company that does not currently use the wharf. One of the operators has also requested facilities for electric vessels, an indication that any investment in on-wharf petrol supply may be short lived. The cost of installation of a petrol supply in a marine setting is unlikely to be less than $150K (but does depend on a number of factors for which there has not been enough information supplied to assess). It is unclear who would be paying for this, however if it was to be the current diesel supplier, the investment would be questionable in the long term. If it was to be the Christchurch City Council then there would be a huge misalignment between the Christchurch City Council's vision toward carbon zero and it's actions. Aside from the huge cost, the risks of installation in this environment are significant. This is reflected in the consent hurdles required for the construction of the wharf structure, let alone the installation of an additional fuel system whether above or below ground. There has already been a huge amount of consideration for the ecological impacts of the wharf rebuild and proceeding with seemingly unnecessary further disruption in this area sounds irresponsible and again, disproportionate to the need. Given this, I have concerns over how “commercial use” categorisation will be applied and enforced? What is to stop a user from obtaining the required fuel card and using the commercial facilities as a recreational user? Although the intention is for this facility to be commercial only, I doubt this will be enforceable long term and the only way to justify the return on investment would be to allow recreational use. The wharf is already a busy place, do we want to encourage more foot traffic when there are other boat launching and loading facilities available in the town? There are significant Health and safety implications of additional recreational vessels using commercial facilities.				

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	Akaroa's key tourism and cruise seasons coincide with the busiest recreational season in the town. With increased foot traffic comes the increased risk from an Health and Safety perspective. With the wharf already busy with cruise ship passengers, fishing vessels and commercial operators, if recreational use was also facilitated (whether intentionally or otherwise), this would also add to the risks associated with a multi-use area. There are also already considerable challenges with vehicle congestion and parking in the area which would only be exacerbated. Recreational vessels are suitably catered for in other areas of the community infrastructure - launch at the Recreation ground ramp or Dalys wharf, fuel at NPD and Duvauchelle for 91 - and attracting all vessels to the main wharf will cause congestion and negatively impact commercial use of the wharf. Increased berth space will be required which could impact on commercial boating operations. *The impact on the NPD Akaroa Motor Garage business directly.* We are concerned on how the duplication of available impact will impact our business. We could choose to take an approach that assumes only a small portion of recreational users would go out of their way to find a way to use this facility. For us to take this approach would be irresponsible. We currently employ 10 local staff year round. Many of them have families, mortgages and some of them are currently completing apprenticeships. This is a big responsibility and relies on our business model working effectively. Fuel is much like "2 for 1" deal in the supermarket mailer, a loss leader, it is a reason to enter the shop and as a result, a customer might buy a drink and a magazine, book their boat trailer for a warrant and an annual service for their car. If one of the cogs in this wheel is removed, the flow on effect could be considerable. We have no doubt that we would experience a downturn in petrol sales in our business if the duplication in supply of fuel was to go ahead. The commercial users of petrol are currently our customers but as also addressed above, it would be remiss of us to see the "commercial use only" as a genuine mitigating factor in the protection of our business from the impacts of petrol being supplied on the wharf. Fuel is not a high margin business, it relies on volume to be a viable service to provide. Sales of petroleum more than double in turnover over the period of (October - April) and a large portion of this can be attributed to petrol sales to recreational boats. This significant lift supports our business to make the most of a peak period of trade in the high season which this community relies on. This lift helps to ease the drop off in the lower season. Without this there could potentially be challenges to our ability to supply all necessary services for the community at other times of the year. The future of fuel and electric or other fuel alternatives means we as a business are forward planning to ensure we can pivot and provide services for the community into the future as these things change and evolve. In order to do this, it goes without saying, we rely on the income of our business to eventually enable us to invest in infrastructure to future proof for our business and our ability to support and serve our				

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	community. Regardless of the “commercial use only” label put on this by the Christchurch City Council, there will inevitably be recreational use so we must consider the impact of this redevelopment on the wider infrastructure and businesses in the community. *Other businesses perspective* Again, we are able to see the benefits for a small number of commercial businesses that would appreciate a more convenient refuelling option. Although we see the supply of petrol on the wharf as something that would have a negative impact overall, even for commercial use, we can understand some businesses may view this as an advantage. As current suppliers of petrol in a small town, we are willing to proactively work with these commercial operators to find and invest in solutions which can improve on how the current facilities cater for them. This would add economic value to all local businesses rather than bring additional tankers over the Christchurch-Akaroa road more often when there is already a petrol supply on the Peninsula. *In Conclusion* Akaroa needs to remain sustainable in the future, this involves maintaining the viability of critical infrastructure. At this time we are well resourced, but developments and the outside influence of a business who does not contribute to our community in any other capacity is a risk to us retaining viability into the future. We would be disappointed to see the Christchurch City Council take such a minority approach to something when we as a private business are planning towards and investing in a more sustainable future. Something according to the Christchurch City Council is an important goal for them also. We intend to continue to oppose this element of the redevelopment and would appreciate further transparency and conversation around the project and other solutions we can find for the people who require this service that do not involve risking our environment and community infrastructure. Yours Sincerely, Nina Wright and Clint Beatson Owner Operators, NPD Akaroa Motor Garage				
44715	See attached submission	Harry	Stronach		Akaroa Ratepayer & Residents Association Inc

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44714	As a commercial user of akaroa wharf its important to have fuel, a crane, loading unloading area, something much the same as we all ready have, just keep it simple.	jason	wright	akaroa	akaroa fishermans association
44712	Black Cat Cruises were the first to offer daily tourism cruises in Akaroa in 1985 and are known as one of New Zealand's first eco-tourism operators. Black Cat have won a number of awards in recent years, both for business excellence within the tourism industry and their commitment to conservation and the protection of the Hector's Dolphins. Black Cat Cruises have owned and occupied one of the buildings adjacent to the wharf since 1990 and have a high reliance on the Akaroa Wharf for our operations. Pre-Covid, over 45,000 visitors experienced a Black Cat cruise or Swimming with Dolphins in Akaroa each year. Whilst Black Cat Cruises generally support the councils plan for the rebuild of the Akaroa Wharf, we wish to submit the following comments: 1. A rebuild in the current location is the most suitable and logical option. The current wharf is a key feature of the town and moving this would have a significant visual impact. 2. We accept the need for a full demolition and reconstruction of a new structure. There will be a large amount of disruption through this method, especially for businesses located on the wharf itself. We need further discussion about the council's plans to enable our business to run; in particular the firm proposal on loading/unloading passengers during the construction phase. In addition, if we are unable to access our building on the wharf, what options are going to be made available. 3. The current agreement between CCC and the private building owners allows for the current wharf to provide support to the building structures. CCC should ensure through their tendering process that continued support of these buildings is allowed for and maintained without causing damage to the buildings or their supporting structure. 4. We are seeking assurance from the council that any work done to the wharf, in particular the demolition and re-piling works, will not damage the infrastructure under our buildings or the buildings themselves, and that any cost for such damage will be borne by CCC. Recent engineering assessments show the piles and buildings in good condition. 5. When finalising the design, it is important to acknowledge that a wharf is, in the first instance, a functional civil asset. Much like a road or bridge, it must first be designed to meet its functional needs utilising the most modern technology available taking into account the harsh marine environment. In this case, the primary use is for the loading and unloading of vessels (both recreational and commercial, aquaculture/fishing and tourism) and safe access for the public. After this can come the aesthetic integration to ensure it is not an eyesore for the community.	Paul	Milligan	Lyttelton	Black Cat Cruises

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	6. We acknowledge that there is some heritage value associated with the Akaroa Wharf. We support the inclusion of design aspects to keep the "look and feel" of the old wharf, but once again stress that this should not be at the detriment of the functional design. Retaining some of the current asset to be used (where appropriate) in construction of the new wharf would facilitate a good acknowledgement of the history of the wharf itself. 7. Of high importance in the functionality of the wharf is its strength and ability to safely accommodate vehicles for loading. This primarily relates to the aquaculture sector who, for many years now, have had to operate an unloading process utilising forklifts running up and down the wharf to unload. This is both time consuming, but also raises extra risk for the public trying to enjoy a stroll down the wharf. 8. As highlighted in the Envisor report into user requirements – the Wharf has seen increased vessel activity in the last decade. This was primarily around the use by Cruise Ship Tenders, but also additional commercial and recreational users. We support the inclusion of a 3rd floating pontoon, and also suggest provision for a 4th should be made. Floating pontoons perpendicular to the wharf itself can be smaller than the current pontoon as would allow for vessels to tie to each side and a 4th "finger" would not have a big visual impact but would ensure the wharf is functional for many years to come without users getting in each others way. Whilst the majority of cruise ships will return to Lyttelton we expect some level of cruise ship activity post covid. 9. When designing these floating pontoons, they should also allow for an increase in vessel size. It is highly likely that within the next 5-10 years, both commercial fishing and tourism vessels will increase in size. 10. Retaining supply of fuel is key. We support the retention of a diesel fuel supply on the new wharf and welcome any additions. 11. Future "fuel sources" should also be considered at the design stage of the wharf. Although some of this technology may not be immediately available, both electrical and hydrogen supply should be considered, and design considerations made for how these can be incorporated in the future without much re-design required. 12. If the wharf is raised 500mm, as planned, the proposed structure would then sit above the level of our buildings. This will create access issues for our customers and present a health and safety issue by creating steps or ramps down to our level. We seek a discussion with CCC on a remedy for this issue created by the new wharf level. In summary, Black Cat Cruises support the general location and concept, but note there is much to still be confirmed, in particular with the private building owners adjacent to the wharf and how the current users of				

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	the wharf will continue to operate during the disruption. We welcome the opportunity to work with CCC to find suitable solutions to these obstacles.				
44711	Refer attached document	Chris	Ford	Wellington	Disabled Persons Assembly
44710	Refer attached document	Victoria	Andrews	Akaroa	Akaroa Civic Trust

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44709	I am a professional marine scientist who has studied Hector's dolphins around Banks Peninsula for almost 40 years. Of particular relevance to the wharf replacement project is that I and one of my graduate students made a very detailed study of the responses of Hector's dolphins to the pile-driving that took place during reconstruction of the cruise ship berth in Lyttelton Harbour. The technology used was impact pile driving. This is the most commonly used approach, but creates very high levels of underwater noise at each strike of the driver. I'll attach two scientific papers we wrote on this topic. The first of these provides detailed measurements of the noise produced and how it propagated within Lyttelton Harbour. The second specifically addresses what effect those noises had on the habitat use of Hector's dolphins in the harbour. In summary, pile-driving significantly changed how the dolphins used the harbour; they were displaced from the vicinity of the pile-driving towards the outer harbour. Considering the importance of Hector's dolphins to Akaroa, both culturally and economically, all reasonable steps should be taken to ensure this does not happen here. From this research base, I make the following recommendations. 1. If possible, screw piling technology should be used. This creates low levels of underwater noise. 2. In terms of underwater noise, vibration pile-driving is no better than impact pile driving, and should not be preferred. 3. If impact pile-driving must be used, the pile-driving operation should take place in winter, when there are far fewer dolphins present in the middle parts of Akaroa Harbour. Professor Steve Dawson	Stephen	Dawson	Akaroa	New Zealand Whale and Dolphin Trust
44708	I am in favour of replacing the Akaroa Wharf. In order to be in keeping with the wharf being in a Marine Mammal Sanctuary, set up to protect Hector's dolphin, it is important to consider the potential impacts on the dolphins. Research in Lyttelton Harbour has shown that Hector's dolphins are impacted by pile driving. There is a readily available alternative, in screw-in piles. These are no more expensive, and much more environmentally responsible.	Elisabeth	Slooten	Akaroa	

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44707	hi there I wish to make a submission in person in front of a full council, rather than have my arguments presented via the community board, as, with the greatest of respect to the latter, i do not believe such a significant and expensive scheme can be adequately debated in that way. The council appear not to have taken on board many of the recommendations of the consultants they have retained - namely; origins, Enviser ltd, Planz and Tonkin and Taylor. Furthermore the adoption of the knuckle, despite claims that it is culturally essential, seems to me to be a thoroughly inappropriate bolt-on design affectation and entirely unsuited to a pseudo heritage design initiative which the council is pursuing. More than any other reason, the health and safety issues which the knuckle will impact on very severely, appear not to have been appreciated by the designers at all. A working wharf has continual heavy traffic to contend with, and this should never be mixed with recreational sightseers, tourists and others who will be encouraged to access the wharf via the steps of the knuckle at precisely its most congested part. I would also like confirmation of the council's pledge that the concrete construction will be faced with timber, in a concession to the wharf's heritage status, particularly the decking. Thank you for your consideration	Michael	Norris	Akaroa	

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44705	I have a home in Akaroa, and have long valued the amenity of Akaroa wharf, and the visual beauty and cultural significance of this historic structure. There is now a proposal by Christchurch City Council to replace the existing structure. As a mother and grandmother, I am concerned both about the safety of our children, and the environmental future of the planet. Therefore, having seen the Akaroa wharf proposal I wish to raise two concerns. Firstly, regarding the creation of an unnecessary, and potentially hazardous, 'crossroads'. Secondly, regarding the apparent use of concrete in the proposed replacement wharf, particularly the 'knuckle' design feature. The 'Crossroads'. Akaroa wharf is very heavily used. It accommodates the needs of commercial fishermen, commercial tourism operators, cruise ship passengers, tourists, recreational users and members of the general public. Therefore there is heavy traffic up and down the wharf, not only significant foot traffic, but also vehicles and machinery, including emergency vehicles. Although frequently heavily congested, the existing wharf has generally coped safely with these large numbers, as the 'traffic' has flowed up and down the wharf. However, the proposed replacement wharf introduces a new design feature, the knuckle, which creates a 'crossroads' at the busy entrance to the wharf. There are wide stepped structures on either side of the wharf, which create a cross route, at right angles to the existing flow of 'traffic'. On seeing the design I immediately envisioned my seven year old granddaughter delighting in running up one side, across the wharf and down the other side. What child (and their dogs) wouldn't love such an adventure, with the temptation of touching water on either side. This is a recreational/tourist location, where families are likely to be relaxed, and less conscious to the need to be alert to 'traffic' hazards. Children dashing across the route of vehicular traffic, clearly creates significant potential risk, and possible fatalities. Therefore I would be grateful to know (contact details above) if the design team has undertaken a health and safety assessment, around the risk to children inherent in the proposed design. Has any alternative design been considered for providing access to the foreshore and water, which not only is safer for children, but also provides disabled access? Concrete. If the cement industry were a country it would be the world's third largest emitter of CO2. It is recognized as contributing 8% of annual global CO2, a greater share than any country other than China or the US. Cement is the basic ingredient of the construction material, concrete. Given environmental concerns about the detrimental effect of CO2 emissions on climate change, countries around the world are actively moving away from the use of concrete in construction projects. For example, France is now requiring all public buildings to be constructed of 50% wood or other sustainable materials.	Kay	Terry	Akaroa	

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	The existing Akaroa wharf is notable for the tactile nature of its wooden construction, which has gained character by natural weathering. The cross-bracing of the proposed replacement wharf does reference this history. However it is concerning that the replacement wharf proposal does not appear to align with current global best practice construction trends, as it appears, particularly the 'knuckle' element of the design, to be constructed of concrete. This seems a lost opportunity to adopt a world-leading sustainable design. World cities are increasingly focussing on sustainability and lower carbon emissions. Indeed, Christchurch City Council declared a climate emergency in May 2019. Therefore I would be grateful to be provided with information (contact details above) about the percentage of sustainable materials that would be used in the proposed replacement wharf, and how this aligns with the Council's 'green' agenda.				
44704	I have had a long association with Akaroa, I first started coming here regularly as a holiday maker in the 1970s, and have been living here full time since 2015. I wish to be heard in support of my submission. In addition to the points below I wish to emphasise that: i. I would not like to see the commercial buildings footprint increase on the wharf. It is starting to feel like Westfield. I was in Russell a year or two ago, which is a historic village similar to Akaroa. The wharf there was pleasantly uncommercialised in comparison. ii. I support the cultural requirement that decking with steps down to the water's edge should be provided near Fisherman's Rest building. The main points are as follows.	Sara	Black	Akaroa	

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	1. The Akaroa Wharf is a highly valued and much loved community resource. It has sustained the livelihood of numerous families in the area for generations as well as providing pleasure to recreational users and visitors. 2. However, while developing the wharf's replacement the Council has largely overlooked the recommendations in the reports that it commissioned including The Akaroa Wharf Conservation Plan May 2019, Origins Consultants, User Requirements Needs Assessment, Akaroa Wharf, March 2021, Enviser Ltd and Main Wharf Akaroa July 29, 2019, Planz Consultants. 3. The council has a responsibility and duty of care with regard to individuals walking on and using the structure. Health, safety and wellbeing should be high priorities. The Council must reduce the element of risk for anyone who accesses or uses the wharf. 4. The Akaroa Wharf is a dual purpose facility, it serves visitors, recreational users as well as commercial operators. 5. Commercial operators necessitate the use of machinery, vehicles, vessels, equipment, tools, pipes, forklifts, delivery and emergency vehicles. A separate access area for these activities is a necessary requirement to ensure a safe working wharf and port facility while members of the public are present. 6. The Knuckle proposal, with steps on either side of the wharf down to the water, will create congestion at its busiest point. It is an unnecessary design feature and it is not structural. 7. The Knuckle, when the wharf is congested with people and children, will impede commercial operations which require the movement of vehicles, trucks and forklifts as well as emergency vehicles attending call outs. 8. Cultural associations relating to the water can be accommodated along the shoreline, not directly on the wharf itself. Alternative locations are readily available in proximity to the wharf. 9. The main wharf forms one of Akaroa's most significant cultural landscapes. 10. Materials used to construct the new wharf should reflect, compliment and be in keeping with the existing historic character of the immediate area. The surface of the wharf should remain hardwood timber as well as railings, seating and detailing. Visual links and references between the old and new wharves should include the use of wood, similar railings and simple shapes for all buildings and benches. Cross bracing below the wharf continues a long established tradition as recommended in the Conservation Plan. Cross bracing also provides visual continuity between the old and new structure.				

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	Colours should remain muted or dark to reflect the wood and character of the old wharf. The old wharf and abutment are highly textured. Sketches of the new abutment and wharf lack character, texture and colour. No further commercial development should be allowed on the wharf itself and existing buildings should not be allowed to expand beyond their existing footprint.				
44703	Council needs to replace the wharf as soon as possible and stop getting further reports which have no conclusions and do not address the issues which have previously presented by those you use the wharf. Council needs to provide an acceptable alternative wharfage facility for the present commercial users so the present businesses do not go out of business which will affect the economy of the whole Akaroa township. (This was mentioned in the November Calibre report 8.2 but not addressed.) The Calibre report does not consider budget requirements for alternative facilities during the wharf replacement and the necessary facilities associated with a working wharf (power, street lighting, fuel, cranage, sewer, seating, access ladders dingy storage, etc). This all needs to be considered in the wharf replacement budget. The replacement wharf should include concrete piles and a full concrete structure which will then allow for the berthing of larger vessels (also hardwood is uneconomical and environmentally unacceptable). The wharf should have a design life of 200 years and the use of repurposed hardwood will not achieve such (unlikely to achieve 100 years). By fitting fender piles at 3-000m centres will provide a visual blanket to the concrete structure and also provide for large yachts to use the wharf (rather than using the proposed floating pontoons). Super yachts would be too large for the floating pontoons. The proposed steps to the norther side of the solid abutment have no practical use and will become slippery and dangerous to persons trying to use them?? (these should be eliminated from any final design.) Just get on and replace the wharf.	Ian	Le Page	Akaroa	
44702	The Akaroa Main Wharf has very high heritage and landscape value – much higher than its value for actual use. Think of Christchurch Cathedral – not much value there for actual use, but very high heritage and landscape values to the City. That is why the Cathedral is being rebuilt in its former style and form. While it stands – and there is no indication of imminent collapse – the Akaroa Main Wharf needs to be retained (although possibly stabilised) in its present form or as close to that a reasonably possible. The plans by the Council seem to miss an important point. Although the structure is called a ‘wharf’, it	Michael	de Hamel	Kaiapoi	

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	actually functions as a 'pier' or possibly 'jetty'. While vessels occasionally lie alongside, and vehicles sometimes move down it, that is for convenience (eg fuelling) and lack of alternatives rather than necessity. The bulk of the wharf's use is actually as a pedestrian walkway and recreational fishing structure. Tour vessels and tenders operate off floating pontoons, with the wharf only providing pedestrian access to these. Fishing and other boats only use the wharf because it is easier than using Wainui or Lyttelton. A relatively small upgrade to the facilities at Wainui (which has much deeper water) would eliminate the need to use Akaroa's fragile wharf and the present safety conflicts between pedestrians and commercial use. The structural requirements for the Wharf to serve as a pedestrian walkway are very different from those proposed. While a few new piles might be needed, the main requirement would only be a series of light-duty pedestrian 'bridges' between stable sections of the historic surface of the Wharf. Yes, if fixed up to a pedestrian standard the Wharf would still be at risk from severe storms and sea level rise effects – but that would be understandable as a natural risk, not like the effects of a contractor with demolition machinery. Money saved from what would be a much cheaper solution could then be spent on upgrading facilities at Wainui where recreational and commercial use do not conflict with each other. See attached photograph of the Wharf's usual function - kids fishing! 				

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44700	I largely support the project and the proposals as in the plan. I made an initial submission in the early stages and then attended the Akaroa Consultation session where I provided feedback. I agree that the best option is replacing the wharf on the current site although I have concerns about the process of doing so. Until recently I was keen on keeping something similar to what currently exists in terms of design and materials but a recent experience has turned that upside down. Due to some surgery I have spent a couple of months on crutches and very limited mobility that made me realise that the traditional wooden surface is a nightmare and even the best is quite unsafe. Gaps, uneven footing, the slipperiness when wet are huge problems. My preference would be for modern composite materials that balance durability with grip, a safe surface, and even some fall protection. I believe it is important that any structure be future proofed and fit for purpose. The wharf(s) in Akaroa have always been first and foremost working wharves and that should stay. They should also be 100% open access - many wharves around the country have limited or no public access and this would be quite unacceptable. I understand that in some cases Health and Safety requirements mean fences/barriers are required along the edges. Again I urge the designers to resist this as ease of fishing and jumping off the wharf are rites of passage for our youth. It is important the council carefully considers the businesses that operate from and on the wharf both during construction and into the future. This is not a simple issue and one which has not, in my view, received sufficient consideration. My understanding is that the existing structures on the wharf have been added over many years in an ad hoc and unplanned basis and the uses have changed over time. I understand they are not consented (and may not need to be) and there is some issues about ownership and control. As the plan rightly proposes to increase the height of the wharf (but please remember accessibility) the future of these structures must be in question. Aesthetically they are of no value and I suspect structurally they may be suspect, but commercially they are of great value. The issue of who pays and who benefits does not appear to be addressed. Fishing, both commercial and recreational, has always been a mainstay of the wharf. In recent times there was controversy when the historic fisherman's landing was built over without consent (and then no subsequent consequences seemed to occur). The crane and fuelling, watering and provisioning systems need to be kept and brought up to modern standards. Again I assume that the council has worked with these groups to find out what is needed. There is the issue of what happens during construction to allow the businesses to survive. Covid has been a huge hit and if the council gets this wrong it could mark the death knell for some. Provision must be made in conjunction with the business to allow them to operate effectively during construction. For the "building based" ones that seem simple. However the various marine operators need access for passengers, suitable arrangements for fuel, water and other services, storage etc. While there are other wharfs available it is important that whatever solution it be in Akaroa to protect the wider businesses. Perhaps the current pontoons could be relocated (perhaps to Dalys wharf or the Yacht Club wharf) with suitable agreements. I'm not sure about the proposals about the standing areas around the start of the wharf. I also urge the	Kevin	McSweeney	Akaroa	

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	engineers to look at the effect of the current solid first 50 m of the wharf. I have a background in ecological sciences and the difference in the tidal areas on either side is fascinating to me.				
44699	I think the Akaroa Wharf should remain as close as possible to it's original design. It is an iconic part of Akaroa and as is mentioned has cultural and heritage significance.	Meg	Errington	Akaroa	

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ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
44698	• I wish to be heard in support of my submission. • I support the submission of the Akaroa Civic Trust. The main points of my submission: • I support the expression of Maori cultural values. However, greater consideration must be shown to the expression of European/New Zealand cultural values and associations. New Zealand is a bicultural-multicultural country. • The knuckle feature introduces a modern design element into a recognised historic precinct. It is not structural and it will add to the cost of the project. Extensive use of concrete is not sustainable which is contrary to the principles of the council's climate change emergency resolution passed in May 2019. • The knuckle will encourage greater recreational use at the entrance to the wharf where it will be in conflict with commercial users which will create an unnecessary element of risk on the part of the council. The real issue is one of public health, safety and wellbeing. • The wharf and new abutment should relate and refer to the historic setting, streetscape and the old wharf (i.e. the use of a timber decking and cross bracing) with regard to the use of materials. • Increasing the height of the new wharf deck by only .5m is insufficient according to the Coastal Hazard report by Tonkin and Taylor and Taylor dated September 2021 (please refer to attachment). If the new wharf is going to remain operable for the next 50-100 years then it must accommodate the projected sea level rise of 1-1.5 metres in the Akaroa harbour area. In my view 1. The Council has overlooked the recommendations of the following reports. a. The Akaroa Wharf Conservation Plan May 2019, Origins Consultants b. User Requirements Needs Assessment, Akaroa Wharf, March 2021, Enviser Ltd. c. Main Wharf Akaroa July 29, 2019, Planz Consultants d. Coastal Hazard Assessment for Christchurch District, Summary Report, Tonkin & Taylor, September 2021 2. As the owner of the Akaroa Wharf, the Council has a responsibility and duty of care with regard to individuals walking on and using the structure. Health, safety and wellbeing should be high priorities. The Council needs to reduce the element of risk for anyone who accesses or uses the wharf.	Victoria	Andrews	Akaroa	

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ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
	3. The Akaroa Wharf is a dual purpose facility, it serves visitors, recreational users as well as a commercial operators. Therefore the Council should construct the wharf in a manner that ensures the safety of members of the public as well as commercial users. a. Safety measures are a requirement for an active, working wharf and port faciality with regard to commercial activity. The future use of the structure should include the needs of fishermen, aquiculture, tourism operators, coastal shipping, passenger transport, cruise tenders, recreational users and members of the public. b. Commercial operators necessitate the use of machinery, vehicles, vessels, equipment, cranes, tools, pipes, delivery and emergency vehicles and forklifts (refer to Enviser report page 14, Table 7: record of infrastructure requirements from wharf users). 4. The Council has not fully considered sea level rise (Tonkin and Taylor CCC Coastal Hazard Assessment Summary Report September 2021, Key Findings, Short Term: now to 2050; 0-20cm sea level rise; Long Term: 2100 and beyond; 1 to 1.5m sea level rise; see attachment). However, the deck of the Akaroa Wharf will increase by only 500 millimetres. 5. The prosed knuckle feature will attract individuals, families and children to congregate at the wharf's busiest point. The knuckle will impede commercial operations including the access of emergency vehicles, delivery trucks and equipment due to congestion on the wharf itself and in the water around the structure. Recreational users including kayakers, swimmers and paddleboarders will be attracted to the knuckle feature in the same area where commercial operators tie up to and depart the wharf. 6. The council's consultation phase, scheduled to take place over the long holiday period, was poorly timed since ratepayers have been distracted with family, friends and vacations. Seeking information from council staff has proved difficult since many remain on holiday and away from the office. In my experience, and in my view, the council's request for consultation often results in a tick the box exercise. The council has devoted considerable time, money and effort in developing the Akaroa wharf proposal over a period of several years and at this late stage I am doubtful that it will take notice of the feedback provided by submitters. The fact that the Banks Peninsula Community Board will make a recommendation to the council on or around February 28, 2022 after considering submitters comments indicates the outcome is a fait accompli. There is no formal hearing scheduled as is normal on matters as important as this. Ratepayers are not being allowed the option of addressing the mayor and councillors on the replacement of the Akaroa wharf which is critically important. The new structure will have a significant impact the community of Akaroa and wider area of Banks Peninsula for the next 50-100 years. The council has already stated that the approval for the design, consent and construction of the new wharf will commence during the first quarter of 2022 according to Next Steps, page 6, Have your say, Akaroa Wharf				

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
	replacement. In my opinion, the consultation exercise is viewed as a necessity to satisfy the requirements of the Local Government Act.				

Submissions received on Akaroa Wharf Replacement, March 2022

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
44696	This wharf is really means more than just 'ICONIC' any alteration to it let alone DEMOLITION!! 'SACRILEGE' This project is going totally 'Overboard'! and total waste of money as it Stands A new wharf is not necessary the existing one can be strengthened with new piles inside the old ones/deck can be modified still using the existing old timbers . Upright timbers/decking planks/piles and all. Replacement project should be Restoration project. I know the wharf well and as an ambassador for the cruise ships, i could see the pit falls of usage by many people being on it at one time. As for maintenance (What real maintenance? yes additional work carried out to accommodate the tender boats for cruise ships/concession businesses. The biggest problem occurred regarding the wharf was having the parallel decking planks over the horizontal ones (It took us (Cruise Ambassadors) It took a long time to get the council to highlight the danger of the difference in depth creating a groove! Eventually it was a painted marker line. Finally re finance for this project. What happened to the thousands of dollars paid by cruise companies for MOORING HARBOUR FEES? AND CONCESSION FEES FOR USE OF WHARF SPACE (Black Cat/ Blue Pearl +others). Save the Wharf/restore not Destroy	JOHN	THACKER	Governors Bay	N/A
44695	I applaud the construction of a new wharf and the design seems strong. In particular: - stepped access steps to the water. - increased pontoons for boat mooring. - retention of the blue sheds. It would be good to see: - more seating on the wharf - a concession for a cafe/bar at the west end of the blue sheds (consider popularity of Harbour). - raised viewing platform at end of wharf, with open-sided pavilion. It would provide an additional visitor experience and reference the pavilion on Daly's wharf.	Peter	Marshall	Christchurch	

Submissions received on Akaroa Wharf Replacement, March 2022

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
44693	I want to be heard in support of my submission and I support the submission of the Akaroa Civic Trust. I am disappointed the council has decided to demolish the old wharf but understand the need to accommodate sea level rise in the coming 100 years. I can see it happening now around the Akaroa harbour. However - increasing the height of the wharf deck by 500 millimetres does not meet the threshold of what is required according to information contained in the Coastal Hazard report by Tonkin and Taylor dated September 2021. Why is the council being so shortsighted? The Akaroa wharf is a lifeline into the future for the long term wellbeing of the community and Banks Peninsula. Freight and passenger service may return to the use of ships. The new wharf will be critical in terms of serving the needs of the area and it will likely need an elevated incline for vehicle access to avoid rising sea levels. I have lived in Akaroa for more than 26 years and I have witnessed how busy the wharf area can become yet the council is proposing to build a concrete decorative add on, the knuckle, at the busiest point at the start of the new wharf. This is madness. It looks like the council sees the Akaroa wharf as being for recreational use but in reality it is a working wharf that has also been used by international cruise ships as a port facility for many years. The Lyttelton Port Company would never be allowed to host recreational use within its confines much less on a working wharf structure. The council should be concerned about public health and safety instead of fussing over decorative features which are unnecessary and potentially dangerous. If the knuckle is built it will attract people to linger and lounge at the very point where ambulances, trucks, delivery vehicles and forklifts drive onto the wharf. The knuckle has no visual relationship to the historic streetscape of Beach Road or Akaroa's historic area. I think whoever came up with the idea must have been looking at photographs of steps down to the water because it is a common trend in European cities. If the council is going to spend over $19 million to build a new wharf then please use hard timber for the decking and cross bracing. Otherwise it will look just like the New Brighton Pier in Christchurch and Akaroa is not Christchurch. The images that I have seen of the new wharf make it look minimal and contemporary whereas the old wharf and general area has a lot of texture and is dark and in terms of colour. The council needs to remember that tourists and visitors come to Akaroa because of its historic character and unique sense of place. The new wharf looks totally out of place in the context of Akaroa. Fishermen and tourism operators have to make a living and the wharf is crucial to many livelihoods and families in the area. Commercial operators should not have to contend with kayakers, swimmers and paddleboarders swarming around and under the wharf as they work nor should they be required dodge people walking on the wharf when they have to drive their trucks and delivery vehicles onto it on a daily basis. The two activities, passive recreation and commercial, need to be safely separated as a matter of urgent public safety. No more buildings should be allowed on the new wharf because it is open public space, tourism operators will take over if permitted to do so and existing building should not be allowed to expand or become larger. The council is on track in terms of turning Akaroa into a Disneyland facsimile and the waterfront	Angus	Davis	Akaroa	

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
	development, created by the former Banks Peninsula District Council about 20 years ago, was the first step in that direction. The town does not need expensive pedestrian build outs and tack tile pavers on every corner. Why does the council waste ratepayers money? It should instead be applied to issues that are important like the conservation, maintenance, landscaping and interpretation of the Britomart Memorial.				
44689	As a consulting engineer, director of OCEL, specializing in marine related work I have the following immediate comments on reviewing the documentation presented. The provision for Sea Level Rise (SLR) is too low at 0.5 m for a structure that can be considered as major infrastructure and can be expected to last for over 100 years. OCEL has done strengthening work for Port Marlborough NZ Ltd. (PMNZL) on the Waitohi Wharf in Picton Harbour that was built of reinforced concrete in 1910 and is still in everyday use. The Akaroa wharf concept is for a fixed structure the deck level of which has not been designed to be adjustable. It cannot easily be jacked up if the SLR provision is inadequate. The evaluation of wharf concepts has not considered floating wharves. A floating wharf adjusts with SLR and allows walk on walk off access the full length of the berthing face both sides of the wharf which is important for tourist type operations and a feature of the existing floating pontoons alongside the existing wharf designed by OCEL. Floating wharves have been designed by OCEL for the PMNZL in Picton, two are in service and floating wharves designed by OCEL have also recently been put into service (2021) in the ports of Greymouth and Westport for the local fishing fleets. The floating wharves were cheaper options than fixed	Gary	Teear	CHRISTCHURCH	OCEL - Offshore & Coastal Engineering Ltd.

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
	wharves. For Akaroa the floating wharf option would allow drive on drive off access via a ramp, walk on walk off access for tourist and recreational vessels and given the $19 million budget allowed for a 155 m long by 8 m wide wharf would be cheaper than the fixed wharf replacement proposed for Akaroa. The cost/m2 rate allowed for the Akaroa estimate is more expensive than the $ /m2 rate that applied for the most recent heavy duty concrete container wharf at Port Otago (2019) designed by OCEL. An OCEL floating wharf option for Akaroa would feature a fixed end caisson like solid exterior structure that provided some wave protection to the berthing faces, featured an attractive architect designed structure to host a restaurant, elevated viewing platform and amenities in place of a blank featureless concrete wharf. The deck on the end structure would be designed to be jacked up to accommodate SLR. The floating elements would be built off site while the existing wharf remained in service minimising changeover time and could at some time in the future be towed to another location as SLR accelerated. If these thoughts were of interest I would be happy to attend a meeting to elaborate further.				
44688	I wish to be heard re my submission, I am concerned that the council staff haven't be transparent with their consultation. We have dealt with the CCC over the last 30 years and found that they give lip service to consultation, so they can tick that box, but it appears they have no interest in what the community want and don't have any interest in saving rate payers money as it isn't there money, that is why our rates in are 3 time what they are in Australia. I have requested information on the cost of repairs to the current wharf and have not been provided with this information. I have also requested it under the official information act and have had no information or reply to my email request, which under New Zealand Government law requires a response and the information supplied. If they have nothing to hide why cant they disclose those figures. This reflexes very badly on the Council staff, as they are not above the law and they seen to forget they are working for the rate payers not the other way around. I don't believe that the cost of repair would be anything like the cost of a new wharf approx $19m, which will blow out as building costs have increased in the last 18months by about 30% and now we have inflation it will increase cost even further. Some factors to consider which the CCC haven't seemed to consider. 1/ The current wharf has been there since the 1880s and families have a deep connection with the current wharf.	Dean	Marshall	Akaroa	

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ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
	The wharf is very much loved by the community and the European history of New Zealand as well as the Maori connect to this current wharf cannot be under stated. 2/ The wharf this one or a new one is a working wharf as well as a recreational wharf. 3/ Has the CCC considered the Akaroa conservation plan may 2019 Origins consultant's, user requirements needs assessment, Akaroa wharf march 21, Enviser ltd and main wharf Akaroa july 29 2019 planz consultants, it doesn't appear so . 4/ I think the designers and council staff have not considered the health and safety aspects of the design. Remember this isn't just a recreational wharf it is a working wharf as well as a tourist wharf. 5/ There are vehicles, machinery and fishing and commercial tourist dolphins operators. There is considerations re access on and off the wharf re safety. 6/The designs I see as an issue that hasn't been thought through well is the following. a/ The fact the new wharf would need to be built 500-600 above current wharf height according to the council staff but in fact when you look at the reports on sea level raises the Councils' own reports say that the sea level will increase up to 1.5 m, in which case looking at the flood maps ,the shops on the main street will be flooded, if the 500-600 or the 1.5 m is to be achieved, how will they get the gradient to work or will they need to build steps or go across the other side of the road to active this height difference. There was nothing in the CCC plans that show how this was to be dealt with. b/ The knuckle, well if the above is to be considered re the height of the new wharf, the Knuckle will be an eye sore. c/ Again as this is a working wharf ,there need to be good access for vehicles including Ambulances and the knuckle will effect access, due to too many people at the entrance to the wharf. d/ The knuckle will be a health and safety issue with the possibility of older persons or children falling down the steps onto the rocks. 7/ As the wharf is one of the main features of Akaroa, it is important to get the materials of construction right. This needs to be in keeping with the historic character of the town. 8/The surface of the wharf should stay hard wood and not the cheaper wood the CCC have been doing repairs with in recent years ,which just have added to the detrition of the current wharf. 9/ All aspects of design should consider the historic references to the current wharf and Akaroa township.				

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ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
	This isn't a small matter and as rate payers we want the best for the community, but we also want a community we can all afford to live in with the ever growth numbers of Government employees both central and local, this isn't guaranteed that we or future generations will be able to afford it so it is all our responsibility to be careful what central and local Government CCC spend. 10/any buildings on the wharf should be in keeping with the character of a historic wharf.				
44681	We would like to be heard in support of our submission. · The Akaroa Wharf is a highly valued and much loved community resource. It has sustained the livelihood of numerous families in the area for generations as well as providing pleasure to recreational users and visitors. · However, while developing its replacement plan the Council has largely overlooked the recommendations in the reports that it commissioned including The Akaroa Wharf Conservation Plan May 2019, Origins Consultants, User Requirements Needs Assessment, Akaroa Wharf, March 2021, Enviser Ltd and Main Wharf Akaroa July 29, 2019, Planz Consultants. · The council has a responsibility and duty of care with regard to individuals walking on and using the structure. Health, safety and wellbeing should be high priorities. The Council must reduce the element of risk for anyone who accesses or uses the wharf. · The Akaroa Wharf is a dual purpose facility, it serves visitors, recreational users as well as a commercial operators. · Commercial operators necessitate the use of machinery, vehicles, vessels, equipment, tools, pipes, forklifts, delivery and emergency vehicles. A separate access area for these activities is a necessary requirement to ensure a safe working wharf and port facility while members of the public are present. · The Knuckle proposal, with steps on either side of the wharf down to the water, will create congestion at its busiest point. It is an unnecessary design feature and it is not structural.	Elizabeth and Peter	Haylock	Akaroa	

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ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
	· The Knuckle, when the wharf is congested with people and children, will impede commercial operations which require the movement of vehicles, trucks and forklifts as well as emergency vehicles attending call outs. · Cultural associations relating to the water can be accommodated along the shoreline, not directly on the wharf itself. Alterative locations are readily available in proximity to the wharf. · The main wharf forms one of Akaroa's most significant cultural landscapes. · Materials used to construct the new wharf should reflect, compliment and be in keeping with the existing historic character of the immediate area. The surface of the wharf should remain hardwood timber as well as railings, seating and detailing. Visual links and references between the old and new wharves should include the use of wood, similar railings and simple shapes for all buildings and benches. Cross bracing below the wharf continues a long established tradition as recommended in the Conservation Plan. Cross bracing also provides visual continuity between the old and new structure. Colours should remain muted or dark to reflect the wood and character of the old wharf. The old wharf and abutment are highly textured. Sketches of the new abutment and wharf lack character, texture and colour. No further commercial development should to be allowed on the wharf itself and existing buildings should be pared back.				
44651	Built in the 19th century, the Akaroa Wharf is protected as an archaeological site under the Heritage New Zealand Pouhere Taonga Act 2014. Under the Act, an archaeological authority is required for demolition of a pre-1900 structure. HNZPT has been in discussions with Christchurch City Council, led by Kristine Bouw and the Heritage Team, and we look forward to continuing this communication as the project, and application for archaeological authority, progresses. The Wharf and surrounding area have high Cultural and Spiritual value and we are encouraged to see Council staff have been working in partnership with, and receiving input from, Ōnuku Rūnanga on the cultural opportunities the new wharf brings. A draft Cultural Design Narrative is underway, and the conservation plan clearly outlines the relationship of mana whenua to this significant area.	Fiona	Wykes	Christchurch	Heritage New Zealand Pouhere Taonga

Submissions received on Akaroa Wharf Replacement, March 2022

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
44648	Submission on Akaroa Wharf Replacement I wish to make a submission on the Akaroa Wharf Replacement as a former resident of Banks Peninsula and a long-time member of the Akaroa Civic Trust who has had an interest in preserving the historic character and general amenity of Akaroa for more than 30 years. I wish to be heard in support of my submission. I concur with the view of the Akaroa Civic Trust that: The Akaroa Wharf is a highly valued and much loved community resource. It has sustained the livelihood of numerous families in the area for generations as well as providing pleasure to recreational users and visitors. I would add that the wharf has been a key part of the historic infrastructure of Akaroa and that the replacement wharf will also contribute to, or harm, the town's visual appeal. To avoid any harm the replacement wharf must look as much as possible like the old wharf, I also share the Civic Trust's opinion that: While developing the wharf's replacement the Council has largely overlooked the recommendations in the reports that it commissioned including The Akaroa Wharf Conservation Plan May 2019, Origins Consultants, User Requirements Needs Assessment, Akaroa Wharf, March 2021, Enviser Ltd and Main Wharf Akaroa July 29, 2019, Planz Consultants. I would submit that 1. The council has a responsibility and duty of care with regard to individuals walking on and using the structure. Health, safety and wellbeing should be high priorities. The Council must reduce the element of risk for anyone who accesses or uses the wharf. 2. The Akaroa Wharf is a dual purpose facility, which serves visitors, recreational users as well as a commercial operators. 3. Commercial use of the wharf involves the use of machinery, vehicles, vessels, equipment, tools, pipes, forklifts, delivery and emergency vehicles. A separate access area for these activities is a necessary requirement to ensure a safe working wharf and port facility while members of the public are present. 4. The Knuckle proposal, with steps on either side of the wharf down to the water, will create congestion at its busiest point. It is an unnecessary design feature and it is not structural. 5. The Knuckle, when the wharf is congested with people and children, will impede commercial operations	John Malcolm	Wilson	Arthurs Pass	

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
	which require the movement of vehicles, trucks and forklifts as well as emergency vehicles attending call outs. 6. Cultural associations relating to the water can be accommodated along the shoreline, not directly on the wharf itself. Alterative locations are readily available in proximity to the wharf. 7. The main wharf is a crucial part of Akaroa's significant cultural landscape. 8. Materials used to construct the new wharf should reflect, complement and be in keeping with the existing historic character of the immediate area. The surface of the wharf should remain hardwood timber as should the railings, seating and detailing. Visual links and references between the old and new wharves should include the use of wood, similar railings and simple shapes for all buildings and benches. Cross bracing below the wharf continues a long established tradition as recommended in the Conservation Plan. Cross bracing also provides visual continuity between the old and new structure. Colours should remain muted or dark to reflect the wood and character of the old wharf. The old wharf and abutment are highly textured. Sketches of the new abutment and wharf lack character, texture and colour. No further commercial development should to be allowed on the wharf itself and existing buildings should not be allowed to expand beyond their existing footprint.				
44645	The wharf in Akaroa is a very important and historical structure and great care needs to be taken when replacing such a structure. It is important that the wharf relates to its history, as much of Akaroa still does, and not become a modern structure because it costs a little less. If the new wharf is built of concrete I think it is most important that wooden planking on the top should be used with as many of the old timbers reinstalled as possible. I find the build out on north side most intrusive and quite out of keeping with the old wharf. If for cultural reasons it is necessary to tie the wharf to the water for access reasons (?) it would much better to run parallel with the north face but coming out from the adjacent sea wall. This would not interrupt the length of the wharf and prevent the new wharf having a most modern appearance	patricia	dart	akaroa	

Submissions received on Akaroa Wharf Replacement, March 2022

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
44642	Akaroa Wharf Replacement I have read with great interest the proposals for the Akaroa Wharf replacement and I would like to add my comments in the hope that more thought can be given to a structure that has been an integral part of the landscape of Banks Peninsula since 1834. But first I would like to quote from the Christchurch City Council in its own words. This is its report from fifteen years ago which is relevant to the present City Council's Akaroa Wharf Replacement plans 'Have Your Say' booklet. The report I am referring to is the Akaroa Harbour Basin Settlements Study Christchurch City Council October 2007. I quote from page 25 of the document. Under the heading 'Historical Context': 'The Akaroa Harbour Basin has a dramatic and nationally important history that shapes the context within which community identity and visitor perception is formed today……'. Under 'Cultural and Built Heritage': 'Akaroa is described as an exceptionally well preserved example of a colonial New Zealand town of the second half of the 19th century…….' Under 'Influence of Heritage on Community Identity': 'The community has expressed a strong desire to maintain the historic character of Akaroa……' As you will appreciate 15 years ago there was already significant concern from Akaroa residents that a town plan was needed hence this strategic planning study of 2007 carried out by the Council. In my submission to you I would like to repeat to you as I am sure many of my friends in this township have, that I, too, feel that the heritage and look of the town is rapidly being destroyed. I will give you just one recent example. When one drives on the main road to Akaroa at the 'entrance' to the township there is a new development on the left-hand side of the road. In my opinion the block of four box-like houses on the hillside represents ugly modernity not in keeping with Akaroa's heritage. There is even an industrial type of heavy fencing around one of these properties. The development screams to me that the Council is not listening to us in its plan of how Akaroa should look and feel. There is a potential problem, in my opinion, when people make the final decisions on town plans when they do not live in the area, and therefore do not have their lives invested within that community. Akaroa residents need to have 'the last word' in future developments of any kind in and around their village.	Jacqueline and Peter	Smart	Akaroa	

Submissions received on Akaroa Wharf Replacement, March 2022

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
	Any future development including the Akaroa Wharf Replacement needs to be in keeping with the historic character of Akaroa that you quoted so many years ago. Let's keep this in the forefront of the minds of councillors before it is too late. I now refer specifically to your proposal on the Akaroa Wharf Replacement. 1. The wharf is one of Akaroa's major draw cards for tourists and locals alike. They enjoy a stroll to the end, to fish, and to admire the views of the harbour and to wonder at our wildlife. They use the wharf to board the ferries, and to shop. However, it must not be forgotten that the wharf needs to look attractive and appealing as well as being functional. However, on page 5 of your 'Have Your Say on the Akaroa Wharf Replacement' booklet the view from the north appears cumbersome. It is a mass of concrete more akin to the brutalist architecture popular in the 1970s. This sort of design has no place in an historic village by the seaside. The new steps appear to lead to nowhere on the north view and are a recipe for disaster. Is there not a danger that children will use the steps as a diving/jumping platform into shallow water? This shared space means that there will be boats arriving and departing the wharf nearby. There is potential for people slipping on the wet steps and as people emerge back up the steps there is a danger of commercial vehicles running them down. With regard to the artist's impression on page 3 where more steps have been designed, this time leading to the beach on the south side. Might I suggest that there is already easy access to the beach and the sea from the main road on the south side. Therefore, you do not need these steps. In summary it is an unnecessary expense for the steps to be built at all on either side of the wharf. 2. Also on the artist's impression on page 5 as you look at the wharf from the road side to the left of the wharf you have two different constructions for the wall, firstly there is a fence, then railings leading up to the building. Would it not be ascetically better to have railings right along that side of the wharf so that people can look down through the railings to the water? You then have continuity of view of the landscape. 3. You mention that the new wharf deck height will be raised by 500 mm. However, I cannot find any drawing in your booklet to show how the main road leading to the wharf will look like. This artist's impression needs to be addressed before any meaningful decisions can be made. Surely this was an essential diagram that needed to be published in your booklet as it is very difficult to visualise how the transition between the main road and wharf will work successfully. 4. I would like to see hardwood used on the wharf floor as it is a natural feature of wharfs around the coasts of New Zealand. This would fit in well with the wharf's heritage. If you are looking for other contemporary examples of this, look no further than the town of Oamaru. The Council is working on its replacement wooden flooring of Holmes Wharf as we speak. They are making a fine job of it. I would hate to see Akaroa's wharf changed to concrete. 5. With regard to the buildings on the wharf it is important that the structures are not oversized in relation to the wharf. If you look at the picture on the front cover of your booklet, the present buildings appear				

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
	oversized. This is not helped by extra box like structures which have been added onto them more recently on the side of the roof facing the wharf. In my opinion, these additions have made the structures appear ugly and out of proportion. I would go as far as to say they are monstrosities. Also, I think it would be more in keeping with an historical perspective if the structures were wooden in appearance and that they had wooden window frames and were painted in heritage colour schemes if they had to be painted at all. 6. If you are intending to give an overview of the history of the wharf, please could you make sure that the interpretation board does not block out the views. The board would be best placed on the side of the building rather than spoiling the views of the landscape looking out to sea. I do hope that you can spare the time to take my ideas on board as it is imperative that we get the look of the wharf right for those who live and travel here and for future generations. Akaroa is already being spoilt by a blanket approach of giving it a look of an inner city ie with the pavements demarked in white and yellow and road speed signage stretching above the eye line like enormous lollipops. Visitors and locals alike are attracted to Akaroa for its heritage. Please do not spoil any more of the place we call 'home'. With extra thought and first-class design, Akaroa could be even more of a draw card for New Zealanders and the World alike. With kind regards. Yours sincerely Jacqueline and Peter Smart				
44638	The Akaroa wharf is of historic significance and a major attraction for tourists as well as a functioning port facility. If it is not viable to repair then any replacement should attempt to replicate the existing one, maximising the use of timber and minimising the use of concrete and steel. Otherwise any link to the past will be lost.	Mervyn	Spurway	Akaroa	

Submissions received on Akaroa Wharf Replacement, March 2022

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
44636	Both Calibre Consulting Ltd Renewal Options and the CCC Akaroa Wharf Replacement booklet give excellent summaries of options and proposals. Despite arguments for retention of historic, cultural and spiritual values, (mere word-play), the practical approach must be paramount. Cost issues too, will take precedence. Concrete piles and beams should be used for strength, longevity, sustainability and the cost factor. I question the need for any more than minimum timber use to disguise the concrete structure. And any timber so used should be recycled from the existing wharf. The tin sheds are an eyesore and have no historic value. Building owners will have the opportunity to re-design during construction. CCC should ensure the new design is in keeping with Akaroa's heritage. Concrete steps from the abutment look like a good option for easy access to the water on the sheltered north side, and the addition of an end T and another pontoon or two would make the wharf more available to the casual user.	Nigel	Ferguson	Akaroa	
44631	I think the Akaroa wharf should be in timber to be in keeping with the historical aspects of the village. Please do not put a hard modern surface such as concrete it would be ugly and aesthetically unpleasing	Hilary	Hancock	akaroa	
44572	The replacement wharf must have wooden decking, there is no place for concrete decking on the replacement of such an iconic structure. The new wharf should continue to cater for a broad range of activities, these activities, commercial and individual, are the current structure's life force. I support steps on the southern side of the wharf giving access to and from the beach in front of Britomart Reserve.	Elizabeth	Mars	Akaroa	

Submissions received on Akaroa Wharf Replacement, March 2022

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
44463	Having read through the current Akaroa wharf proposal, I would like to strongly object to the use of concrete instead of wood. We will end up with a wharf that looks like New Brighton Pier and is not in keeping with the historic French theme of the village. Full Restoration of the existing wharf with like for like hardwood timber would be the best option but full replacement with a mixture of concrete and hardwood timber (visible) would be acceptable and concrete would not be acceptable. members would be hardwood) ▪ Full Replacement with modern reinforced concrete The consultation document also considered three potential locations	Wendy	Risdon	Anne	
44434	There has been discussion over many years relative to the construction of a stone breakwater in the general direction from the end of the main wharf structure towards the lighthouse, with appropriate gaps in the breakwater for entry and exit. The purpose of the breakwater would be: -to improve the safety for all forms of boating and provide a safe haven for boats from the existing wild weather fluctuations of the area, as well as the effects of future global warming. -to protect the new wharf from the wild weather fluctuations of the area, as well as the future effects of global warming. -to eliminate or reduce tidal and weather surges in the wharf area and enhance the safety and comfort of onloading and offloading of passengers -to provide a safe haven for moored boats that are otherwise exposed to extreme weather conditions. I would like to see a future breakwater proposal mentioned and considered in the wharf design to ensure that the wharf design is compatible with the future development of a breakwater. Akaroa Harbour is a beautiful environment that requires careful long term planning, and a breakwater would considerably enhance both the safety aspects mentioned above, as well as the aesthetic and natural beauty of harbour.	Paul	Burrowes	Christchurch	
44356		Michele	Moore	Hororata	

Submissions received on Akaroa Wharf Replacement, March 2022

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
44345	1. While construction is in progress, we as operators (commercial) from the Wharf would like Drummonds wharf to be upgraded for ourselves and Black Cat Group so we can continue to trade. At the end of construction this would leave a community asset for future use. 2. We are current tenants of the Council owned "Weighbridge" small building at the entrance to the main wharf. During construction we would to close this ticketing office and have the Council provide a container/kiosk to use as a ticketing office close to Drummond's wharf. 3. We would like the floating platforms to be at 90 degrees to the new wharf and to be one simple length of 30m with staunching's and white fenders - not black. 4. We would like fuel, water, sewerage and electricity to be accessible to all users	Hugh	Waghorn	Akaroa	Akaroa Dolphins
44154	It is really vital for boating safety that passengers can be loaded/unloaded on and off the three pontoons into private/recreational vessels, as Akaroa has very poor public access for this purpose at any of the public slipways in Akaroa at all, especially for the elderly or handicapped persons, and for the unloading of injured or medical assessment patients too at the main wharf The Enviser report dated 03/09/21 is also very misleading with respect to Page 29, refering to the Rec Ground ramp as "Dual access" when one side would never meet any public Health & Safety requirements ever. There is no "Floater" attached to either side on the Rec ramp, which is also a Health & Safety matter, and extremely poor washdown facilities provided at this ramp or anywhere nearby. Simon Duncan - Westpac Rescue Helicopter - general manager	Simon	Duncan	Christchurch	GCH Aviation Limited

Submissions received on Akaroa Wharf Replacement, March 2022

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
44145	The ramp and wharf facilities for recreational boat users are below standard (steep, pot holed, drop offs, vertical ladders, tidal and difficult to access at certain tides). The main wharf is seldom used by recreational boat users due to the proximity to car/ boat trailer parking. This submission proposes that the ramp and wharf facilities for all users in the Akaroa area are considered and following aspects incorporated 1. A ramp that can be used in all tides. Use of Daly wharf ramp is unsuitable and dangerous and means users tow boats through the main street and and down past Ma Maison and often long ques result 2. A pay to use boat wash is installed to discourage unlimited boat washing on the streets from town supply which is in short supply and often has restrictions on it. 3. Suitable floating wharf modules are installed so access to boats is safe and functional. It is impossible for elderly or disabled persons to get onto boats from Dalys or Main ramp jetties at certain tides. I know is outside your main wharf scope but a quick look around any other port in NZ would see facilities like those proposed and surely we deserve better in Akaroa.	Charles	de Lambert	Akaroa	
44057	Please consider options for cruise ship tender berthing	D	Coulter	Christchurch	
44017	Would it not be possible to build the new wharf alongside the existing one for the majority of it's length, allowing for continued use of the existing structure while the majority of the new one is built and utilising the existing wharf as a building platform, then only the short tie section to shore needs to be out of action for a short period at the end of construction. https://unitedcivil.co.nz/project/paihia-wharf/	Christopher	Marett	Christchurch	
43985	I just have one question. The dimensions of the wharf will be the same. Is provision made for future extension of the wharf to allow for extended use? e.g. as a marina, or to accommodate expanding activities such as boat tours.	Keith	Jessop	Christchurch	Flow Kayaks 2017 Ltd

Submissions received on Akaroa Wharf Replacement, March 2022

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
43951	I would like to see the current Wharf repaired or replaced on it's existing site. Having 2 wharfs means having to maintain both and is not necessary.	Ian	Little	Christchurch	
43878	You need to make the new wharf wider, at least out to the private buildings. When I was last there pre-pandemic, during peak tourist season, there was a large number of pedestrians on the wharf and it was very crowded. If this new wharf is intended to last a long time (many decades), it needs to be able to cater for future growth in users, so that it is not so crowded.	Mark	Relling	Christchurch	
43877	The new wharf, while likely fully planned, needs to provide a larger floating pontoon for leisure craft from around the harbour. The ability to safely moor for 2- 6 hours at the wharf is currently challenged by lack of space. Increasing capacity will encourage increased spend on F&B and the like by locals and holiday makers. Currently the floating pontoon is too small or not available at all when cruise ships are in. The need to keep adjusting mooring ropes based around tidal movements for small craft on a high wharf just does not work. By increasing wharf mooring, we will look to reduce road traffic in the harbour area, and potential carbon foot print.	Anton	Wilke	Christchurch	
43875	We support this proposal as it currently stands. Thank you for your time with this. Mary and Peter Gluyas	Mary	Gluyas	Akaroa	
43850	The explanation provided in the feedback plan of the need for the wharf replacement and the look of the new wharf satisfy my interest.	Graham	Ewing	Christchurch	

Submissions received on Akaroa Wharf Replacement, March 2022

ID	Please provide any feedback you have on the Akaroa Wharf replacement project	First name	Last name	City/Town	Name of organisation
43818	As an owner of property in Akaroa my wife and I would like the new wharf to have stalls (small shops) available to sell locally made arts and craft as well as local produce. We would also like to see safety railing at the end of the wharf to make fishing safer for children and older people. We noted kids fishing had nothing to hang onto. We would also like to see cruise ships back in the harbour so docking for the ships tender boats would need to be catered for. If business used the retail stalls and the cruise ships were charged for docking tenders this would help pay for the new project. Second submission. We would also like to see extensive lighting for use of the wharf at night preferably using solar lighting and an area where a band etc could operate. Akaroa needs a better night life and the wharf could help with that.	Ian	McPHAIL	Akaroa	

Akaroa Ratepayers and Residents Association Inc

To: Christchurch City Council
PO Box 73016
Christchurch 8154

Date: 31 January 2022

Attn: Ms Ann Tomlinson, Senior Engagement Advisor

SUBMISSION REGARDING THE AKAROA WHARF REPLACEMENT

The Akaroa Ratepayers and Residents Association (ARRA) is an Incorporated Society that has been established to promote the interest and wellbeing of the community in the Akaroa area. This submission is made on behalf of the members of this organisation, and we believe this also represents the general interests of the wider community.

This submission has been prepared by Harry Stronach, the President of the Society. The preparation of this submission has been severely constrained by the December flooding event on the Peninsula, and a supplementary submission may be made in due course.

We wish to be heard in support of this submission.

Key Points

The Akaroa wharf is of fundamental importance to the town. Take the time to get it right, so that we can all be proud of the result.

Background

The main wharf in Akaroa has been in operation for around 130 years, and is currently in fairly poor condition. Christchurch City Council (CCC) has proposed that the wharf should be rebuilt, in broadly similar size and location as the existing wharf, and has invited public comment. The comments of ARRA are given below.

It is important to note that the wharf is a dominate feature and focal point of the town, and any major rebuild or replacement will have a long life expectancy and will “set the scene” of the Akaroa waterfront in a rather permanent fashion.

Community Asset

The wharf is a community asset. Christchurch City Council may be the current custodians, but they are simply holding the ownership of the wharf in trust, on behalf of the community of in the Akaroa area. Decisions on the future of the wharf must be driven by community consensus, with the opinions of council staff being useful inputs rather than determining factors.

Current users of the wharf will clearly have valid and important contributions to make, noting that those parties will generally have a focus on their own particular requirements. Such inputs need to be balanced against the fact that the current users are only "temporary residents", in the context of a wharf that is likely to exist for over 100 years. We believe that it is important that the design process takes a very broad perspective on future wharf usage, with input from the wider community being given substantial weighting.

What is the purpose?

The wharf is primarily a structure for commercial vessels, including fishing boats and tourism operators, but it is also used by private vessels, both local and those visiting Akaroa. It is also a recreational area for the public, whether simply wandering, taking in the sea air, or dropping a fishing line over the edge[1].

CCC commissioned a "User Requirements Needs Assessment" which was presented in March 2021, and is referred to as the Envisor report. That study was rated as "fair enough", as far as assessing the current operations are concerned.

On the matter of analysis of trends, likely future growth and future activities the Envisor report was very weak and lacked any real strategic analysis. These aspects need to be evaluated in far more depth, given the importance of the wharf project to the township.

In particular, the project needs to be far more ambitious regarding the maximum sized vessel that can be berthed. For example, the sail training vessel Spirit of New Zealand would[2] use the wharf when they come to Akaroa if they could do so. Currently, vessels of that size (33 m on deck and 4 m draught) are not permitted to use the wharf due to structural issues. The chatter in the marine industry suggests that we are going to see more sailing vessels of broadly that size in NZ waters in coming years, plus many more medium-sized private vessels.

There would be widespread support from the community for such visiting vessels to use the wharf. The regular talk about attracting high value tourists to the area could be given some practical meaning, by providing a wharf that can accept private vessels (so called superyachts) of an appropriate size.

The use of the wharf as a "tender terminal" is not a prime consideration, and a concept for sustainable tourism in Akaroa needs to be developed and agreed before any particular consideration is given to tender operations to the Akaroa wharf. We note that the cruise ship industry does not have any ownership stake in the infrastructure in this area, and when approached on this specific subject they declined to make any contribution whatsoever to the local community.

Where does all this fit into the big plan?

We just do not know, because there is no big plan, no common strategic vision, for the Akaroa town and surrounding area. That is a major concern.

[1] Or jumping over the edge, depending on your age and the water temperature

[2] Confirmed by discussions with the Spirit of Adventure Trust, which operates the vessel

It is essential that we have a comprehensive strategic plan for the entire township, before the wharf project proceeds. The Envisor report seems to think it is going to be "business as usual" regarding cruise ships - which is completely at odds with the ambitions of most residents. There are also related issues regarding the wisdom and risks of mixing commercial activities (unloading mussels etc) and recreational activities, on a wharf that is open for general public access,

Private Buildings

There are privately owned structures adjacent to (and partly connected to) the wharf, which perhaps have not been issued with consents in a proper manner, but rather have evolved over time.

Any complete rebuild of the wharf will clearly enhance the value of those buildings and the associated businesses. In fact it is clear that those enterprises benefit greatly from the wharf and, with their numerous clients, are major wharf users.

From the ratepayers' perspective there is an issue as to whether those building owners have been, and will be, paying an appropriate and fair proportion of the associated costs. Or are they going to get a free ride courtesy of the ratepayers?

The proposed rebuild of the wharf is an ideal and appropriate opportunity to remove any illegal and/or non-compliant structures, regardless of any past history of acquiescence by CCC. Given that this is a matter of public interest, and the ratepayers are paying, we expect to see complete transparency on this subject from CCC.

Wharf Height

We all know that there really is going to be sea level rise during the life of this new wharf. But exactly how high that rise will be remains uncertain, and that uncertainty becomes speculation as we peer further into the hazy future.

CCC have accepted a consultant's suggestion that an increase in deck height of 500 mm is going to be the "right" decision. Our view is that the science of climate change impact is not yet mature enough to make that call, and it could be that 500 mm will be seen to be completely inadequate, or excessive, in say 30 years time.

In addition, there has been no visible thought given to the costs associated with an increased height, the most obvious being the increased construction costs. There are also real, although less quantifiable, costs associated with the inconvenience of having to go up even 500 mm each time you walk down the wharf, just so that you have further to climb down[3] to get to your vessel.

A more prudent solution would be to design a fixed-height underlying structure, with a deck that could be raised at a future date if that proved necessary, say at 25 year intervals. Such

[3] And associated safety risks, whenever ladders and ramps are involved. Why deliberately make a ladder higher than necessary, in a situation that may exist for decades, if it is not proven to be necessary. Nuts.

an approach may have no appreciable increase in building costs, given the savings associated with lower initial height, and with the cost of any future work being heavily discounted in present value terms. From an engineering perspective it would not be difficult to put this concept into practice.

Wharf Appearance

We support the view of the Akaroa Civic Trust and other submitters, in that the layout of the wharf should largely follow the existing arrangement, and the appearance of the wharf should be a meaningful enhancement to the style, character and heritage of the town.

Some aspects of the design concepts presented to date, such as the "knuckle" are simply silly, and show an inadequate grasp of the design priorities[4].

The existing wharf has a 30 m long solid abutment (sometimes referred to as a quay) at the landward end. In the design concepts shown to date, that feature is reduced or even eliminated, which would be a retrograde step. Apart from detracting from the overall appearance, the abutment provides a degree of shelter to vessels and persons on the northern side. Given that the abutment is by now long established, its absence would be likely to change the local waterflows and deposition of marine materials in unpredicted ways.

The detail design of the wharf needs to take account of all user requirements, and public concerns, and we look forward to meaningful discussions on these aspects.

Construction Materials

There seems to be an assumption that concrete and/or steel will be the materials of choice, at least for the main structure. The alternative option, of using hardwood timbers seems to have been relegated as being too difficult, or perhaps old fashioned, or high maintenance. While the timber option does certainly require more planning, suitable timbers are known to be available from suppliers in Australia.

And look, CCC has a "Climate Resilience Strategy" document, and an ambition of achieving carbon neutrality by 2045, and here is an opportunity to put some real meaning into those feel-good ideas. Construction using suitable timber as extensively as possible utilises a renewable resource, and is a carbon sink. On the other hand the industries that produce concrete and steel are major greenhouse gases emitters. I think it is fairly obvious which side of that debate we want to land on.

Spend a moment to contemplate just how good-looking a new timber wharf could be, and how it would enhance the appearance and style of the town.

And then go and take a look at some concrete wharfs that have been built recently in NZ, and you may realise just how great a mistake the concrete version would be.

[4] And a fundamental lack of common sense

Environmental Impact

The CCC documents available to date seem to provide no contemplation of the effects of the project in one important stakeholder group – the dolphins. There is no doubt that the dolphins are star players in the Akaroa environmental and tourism scene, and so some consideration is certainly due[5].

At the same time there is increasing concern in the technical press about the deleterious effects of underwater noise on marine mammals. Given the fact that the dolphin population has been declining in the harbour over recent years, it would obviously be counterproductive to undertake a major pile-driving project if that could be avoided or minimised.

The option of retaining, or even extending, the solid abutment needs to be seriously considered, as that would be likely to reduce piling activity and noise. In addition, the types of piles used, and the installation machinery and techniques need to be selected specifically with a view to minimising underwater noise.

Consultation Process

Recently we make a submission to CCC on the subject of their revised "Community Strategy" which had much talk about partnerships, and strengthening communities. There was no complaint about the CCC strategy, but it's the actions that count.

The subject of the Akaroa wharf replacement is a prime opportunity for the CCC to develop a meaningful partnership with our community, and both parties would end up strengthened as a result.

Sadly, the process to date has simply following the standard CCC format. Consultants have been no doubt well paid, there have been long periods of silence while staff presumably beaver away at something, with occasional "Have your Say" consultation exercises that are widely regarded by the ratepayers as a sham.

With this project we are talking about spending around $20m, which will ultimately be funded primarily by ratepayers[6], on creating an asset that will have a likely life of over 100 years. The subject is of fundamental importance to the future of Akaroa, and we therefore expect that an appropriate level of strategic thought and visions is applied to this project. But has this been happening?

There is an opportunity here for CCC to do so much better. We look forward to seeing a more meaningful engagement process with the community as this project continues.

Submission by

Harry Stronach, (Akaroa Ratepayers and Residents Association Inc)

[5] Of course, the effects that the wharf building and piling noise will have on humans in the area has not been considered either

[6] It is true that wharf users also pay fees in various ways, but in practice that is unlikely to even cover ongoing maintenance costs rather than contribute to the capital costs. CCC have not provided any detail on the financial framework around the wharf replacement project.

Disabled Persons Assembly NZ

January 2022

To Christchurch City Council please find DPA's submission on the Akaroa Wharf Replacement

Disabled Persons Assembly NZ

Contact:

Chris Ford

Regional Policy Advisor

[redacted]

Ingrid Robertson

Kaituitui

[redacted]

Introducing Disabled Persons Assembly NZ

The Disabled Persons Assembly NZ (DPA) is a pan-disability disabled person's organisation that works to realise an equitable society, where all disabled people (of all impairment types and including women, Māori, Pasifika, young people) are able to direct their own lives. DPA works to improve social indicators for disabled people and for disabled people to be recognised as valued members of society. DPA and its members work with the wider disability community, other DPOs, government agencies, service providers, international disability organisations, and the public by:

telling our stories and identifying systemic barriers

developing and advocating for solutions

celebrating innovation and good practice

The submission

DPA welcomes the opportunity to submit on the Akaroa Wharf replacement. This new replacement wharf will ensure that all disabled people and their whanau will be able to access and enjoy the events Akaroa has to offer. It will also cater to the growing number of disabled people who will visit this great tourist destination in the years ahead.

The United Nations Convention on the Rights of Persons with Disabilities (UNCRPD)

The UNCRPD Articles most relevant to our submission are:

- Article 4.3 Involving disabled people and our organisations in decisions that affect us
- Article 9 Accessibility
- Article 9: Accessibility
- Article 19: Living independently and being included in the community
- Article 20: Personal mobility
- Article 30: Participation in cultural life, recreation, leisure and sport

New Zealand Disability Strategy 2016-2026:

- Outcome 5 - Accessibility

DPA's recommendations

Recommendation 1: DPA strongly recommends that the wharf is repaired and made accessible for all users, and this especially includes disabled people who are mobility impaired such as, for example, people using wheelchairs, mobility scooters, and walking frames as well as for people pushing children's strollers.

Recommendation 2: DPA welcomes proposed changes to the height and width of the replacement wharf. It appears to us from the architect's drawings on the website that it will be made wider than the current wharf in order to accommodate more people and this will be beneficial for disabled people who use wheelchairs, mobility aids (such as walking frames) and people pushing children's strollers. Indeed, ensuring full and safe accessibility for all pedestrians and other wharf users will be vital.

Recommendation 3: DPA strongly recommends the availability of wheelchair and mobility aid user-friendly hoists to access boat trips departing from the wharf.

Recommendation 4: DPA strongly recommends that there be an accessible entrance created for everyone to commercial sites on the wharf, and this includes for disabled people using mobility wheelchairs, scooters and other aids as well as blind and low vision people.

Recommendation 5: DPA strongly recommends that there be tactile strips placed at strategic points along the wharf and jetty area to accommodate the needs of both blind people and low vision people navigating the area.

Recommendation 6: DPA strongly recommends the incorporation of safety features along the wharf including the erection of small wooden barriers to prevent people (including disabled people) from falling into the water and the placement of warning signs in accessible formats (i.e., New Zealand Sign Language) to indicate elevated risk areas.

Recommendation 7: DPA strongly recommends that seating be placed at strategic points along the Akaroa wharf of varying heights (either higher or lower), and these should include armrests so that people with mobility impairments, children and older people can easily get in or out of the seats.

Recommendation 8: DPA strongly recommends that there are sufficient mobility car parking spaces made available to accommodate the growing number of disabled visitors to the wharf area and that these be placed near the wharf.

Recommendation 9: DPA strongly recommends that it be involved alongside other disabled people's organisations (DPOs) as part of a comprehensive co-design

process and these organisations include People First, Deaf Aotearoa, Muscular Dystrophy Association, Kapo Maori and Blind Citizens. To this end, our local Kaituitui and DPA members are available to become involved in this project to ensure its accessibility.

Conclusion

DPA welcomes the City Council's proposal to replace the ageing Akaroa Wharf with what will hopefully be a more inclusive, accessible and safer wharf designed to meet the needs of both the Akaroa community and visitors going forward.

DPA looks forward to hearing the Council's response on our submission.

AKAROA
CIVIC
TRUST
P.O. Box 43 Akaroa 7542

January 30, 2022

Re: Executive Summary - the Akaroa Civic Trust's Akaroa Wharf Replacement Submission

The Akaroa Civic Trust has an established track record of community and public service for more than fifty two years. In our view the Council has not to fully considered important issues that will significantly impact the health, safety and wellbeing of the community as well as anyone who uses the proposed new Akaroa Wharf.

The Akaroa Civic Trust

- Supports the expression of Maori cultural values.
- Encourages more consideration of the expression of Pakeha/European cultural values.
- Is concerned about the "Knuckle" feature of the new wharf as it introduces a modern design element into a recognised historic precinct.
- Is concerned, for health and safety reasons, about encouraging more recreational use at the entrance to the wharf where it will be in conflict with commercial users.
- Strongly encourages the use of materials and design elements that refer to the historic setting, streetscape and wharf (the inclusion of a timber decking, cross bracing).
- Notes that the new wharf is to be built .5m higher than the existing to allow for sea level rise, but that predictions are for a much greater increase in sea level over the life of the new wharf.

<u>The main points of our submission are as follows</u>.

1. The Council appears to have overlooked the recommendations of the following reports.
    a. The Akaroa Wharf Conservation Plan May 2019, Origins Consultants
    b. User Requirements Needs Assessment, Akaroa Wharf, March 2021, Enviser Ltd.
    c. Main Wharf Akaroa July 29, 2019, Planz Consultants
    d. Coastal Hazard Assessment for Christchurch District, Summary Report, Tonkin & Taylor, September 2021

2. As the owner of the Akaroa Wharf, the Council has a responsibility and duty of care with regard to individuals walking on and using the structure. Health, safety and wellbeing should be high priorities. The Council needs to reduce the element of risk for anyone who accesses or uses the wharf.

3. The Council should construct the wharf in a manner which ensures the safety of members of the public as well as commercial users. <u>The Akaroa Wharf is a dual purpose facility, it serves visitors, recreational users as well as a commercial operators</u>.

    a. Safety measures are a requirement for an active, working wharf and port faciality with regard to commercial activity. The future use of the structure should include the needs of fishermen, aquiculture, tourism operators, coastal shipping, passenger transport, cruise tenders, recreational users and members of the public.

    b. Commercial operators necessitate the use of machinery, vehicles, vessels, equipment, cranes, tools, pipes, delivery and emergency vehicles and forklifts (refer to Enviser report page 14, Table 7: record of infrastructure requirements from wharf users).

4. The Council has not fully considered sea level rise (Tonkin and Taylor CCC Coastal Hazard Assessment Summary Report September 2021, Key Findings, Short Term: now to 2050; 0-20cm sea level rise; Long Term: 2100 and beyond; 1 to 1.5m sea level rise). However, the deck of the Akaroa Wharf will increase by only 500 millimetres.

5. The prosed Knuckle feature will attract individuals to congregate at the wharf's busiest point.
    In our view, the Knuckle will impede commercial operations including the access of emergency vehicles, delivery trucks and equipment due to congestion on the wharf itself and in the water around the structure.

AKAROA
CIVIC
TRUST
P.O. Box 43 Akaroa 7542
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January 30, 2022

Ms Ann Tomlinson, Senior Engagement Advisor (email: Ann.Tomlinson@ccc.govt.nz)
Akaroa Wharf Replacement
Christchurch City Council
PO Box 73016, Christchurch 8154

Submitter: The Akaroa Civic Trust, PO Box 43, Akaroa 7542
Contact: Victoria Andrews, Deputy Chair, [redacted]
Mike Norris, Chairman, [redacted]
Paula Comerford, Secretary, [redacted]

☑ The Akaroa Civic Trust wishes to be heard in support of its submission.

Introduction
The Akaroa Civic Trust is a volunteer organistation that has been working to preserve the historic character and natural amenity of the town and surrounding area since 1969. Membership is composed of local residents as well as ratepayers living in Christchurch and around New Zealand. Some members live overseas and visit Banks Peninsula whenever possible.

Akaroa Wharf Replacement Submission
Thank you for the opportunity to comment on the Akaroa Wharf Replacement proposal.

The Civic Trust acknowledges and supports the expression of Maori cultural values relating to the Akaroa Wharf, harbour and surrounding countryside as well as the expression of European heritage values and cultural associations. In the context of the Akaroa Wharf, appropriate bicultural interpretation panels and markers can be located in close proximity or at the Britomart Reserve.

In our view the Council has not to fully considered several important issues which will impact and significantly alter the visual character and amenity of the new wharf with regard to the existing heritage setting and historic streetscape.

The main points of our submission are as follows.

6. The Council appears to have overlooked the contents and recommendations of the following reports.
    a. The Akaroa Wharf Conservation Plan May 2019, Origins Consultants
    e. User Requirements Needs Assessment, Akaroa Wharf, March 2021, Enviser Ltd.
    f. Main Wharf Akaroa July 29, 2019, Planz Consultants
    g. Coastal Hazard Assessment for Christchurch District, Summary Report, Tonkin & Taylor, September 2021

7. As the owner of the Akaroa Wharf, the Council has a responsibility and duty of care with regard to individuals walking on and using the structure. Health, safety and wellbeing should therefore be high priorities. The Council needs to reduce the element of risk for anyone who accesses or uses the wharf.

8. The Council should construct the wharf in a manner which ensures the safety of members of the public as well as commercial users. The Akaroa Wharf is a dual purpose facility, it serves visitors, recreational users as well as a commercial operators.

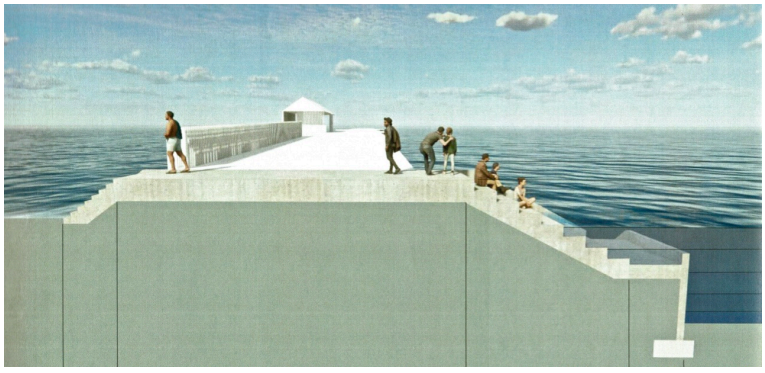
    c. Safety measures are a requirement for an active, working wharf and port faciality with regard to commercial activity. The future use of the structure should include the needs of fishermen, aquiculture, tourism operators, coastal shipping, passenger transport, cruise tenders, recreational users and members of the public.

    d. Commercial operators necessitate the use of machinery, vehicles, vessels, equipment, cranes, tools, pipes, delivery and emergency vehicles and forklifts on the wharf (refer to Enviser report page 14, Table 7: record of infrastructure requirements from wharf users).

Ambulance attending a call out March 2019

    e. A separate operational access area is a required to ensure a safe working wharf and port facility. Providing this space will alter the appearance of the structure, especially if the wharf is to be 'future proofed' for the long-term use and benefit of the community for the next 50-100 years.

The Civic Trust has reservations regarding the Knuckle design feature (referred to as Option A, below, although no other 'option' has been presented for consideration or discussion).

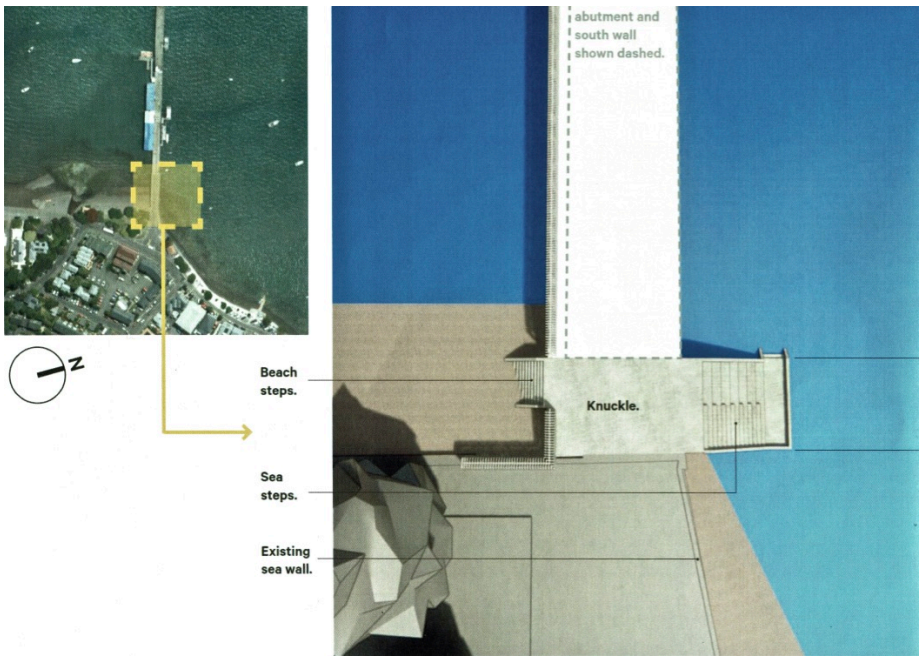


The start of the wharf is often a location of congestion.

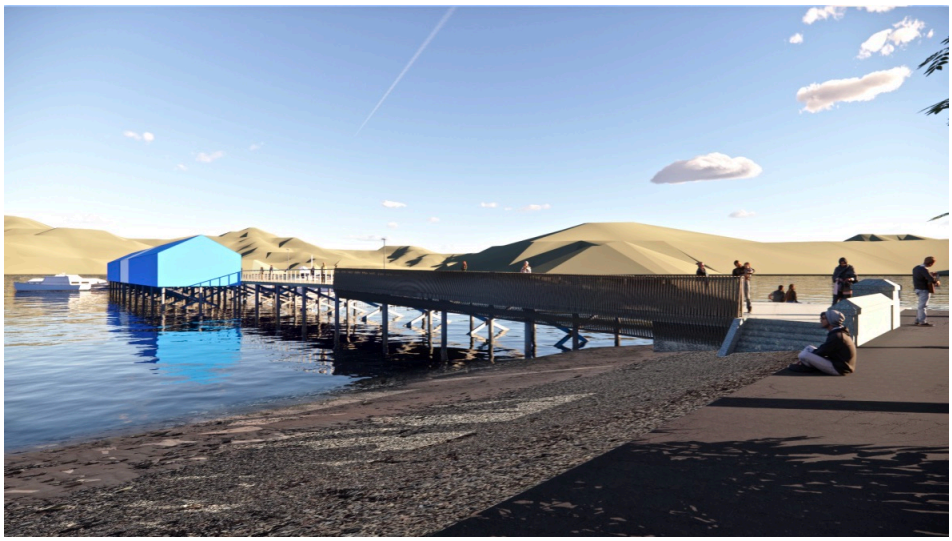
The Knuckle will encourage individuals and children to gather in the vicinity.

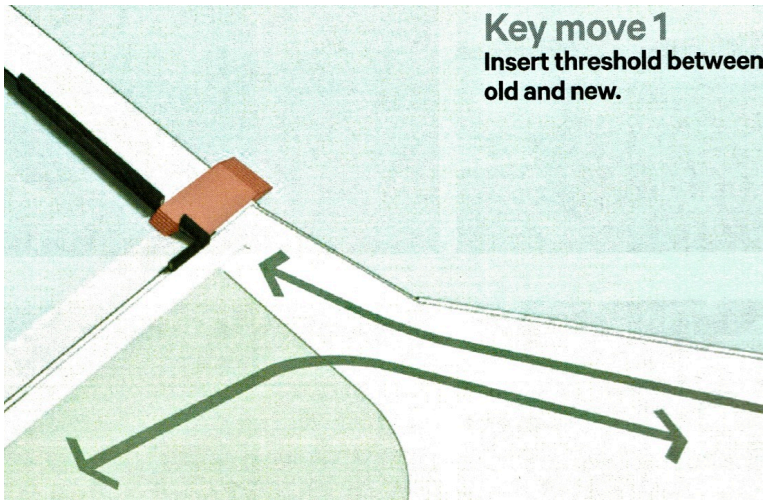
Option A, Isthmus, September 6, 2021

In our view, the Knuckle requires an independent assessment with regard to risk and safety issues.



Images courtesy Christchurch City Council, December 2021





Key Move 1
Insert threshold between old and new
Isthmus, September 6, 2021

The concrete Knuckle is a design concept developed by Isthmus. Timber laid in a contrasting direction could be used instead to signify the demarcation between old and new at a far lesser cost and with a reduced degree of visual impact.

The area where the abutment commences experiences a high degree of activity and at times is heavily congested, see image below. (photos: Victoria Andrews)

December 2018


Kayakers, Akaroa Wharf 2022

Maritime NZ and Environment Canterbury (ECan) should be consulted in terms of providing expert advice with regard to the management of water-based activities i.e. boats used by tourism operators, scientific vessels, recreational users and cruise tenders are being used in close proximity to kayakers, paddle boarders and swimmers (noting that the Council pays ECan to monitor the use of the wharf when cruise ships access the harbour).

In our view, the Knuckle will attract and encourage greater recreational use under and around the wharf, which will bring people into potential conflict with commercial vessels.

The Council needs to be mindful that some visitors, including families with young children, may not have adequate swimming skills to support themselves in the harbour as reported in recent news articles (Holiday drowning toll up 180 per cent on five-year average, Press, Jan 6 2022.The drowning toll for the official holiday period is up 180 per cent on the five-year average.)

The Knuckle is intended to provide access to the 'beach' and water as an expression of culture associations, however public access to the water is already available in close proximity to the wharf as seen in the image below. (photo: Victoria Andrews)

South side of the Akaroa Wharf next to the Britomart Reserve, 2022

Location of the Knuckle at the south side of the wharf.

The north side of the wharf consists of larger rocks along the shoreline.

No consideration appears to have been given to sea level rise with regard to the low seawall, Britomart Reserve and access to the shoreline. (Refer to Appendix A)

In our view, the Council should reduce the element of risk of people gathering a the abutment and the start of the wharf, which is its most congested point. The wharf is a working area that necessitates the use of vehicles, machinery and equipment.

- Access to the shoreline and water is available at alternative locations. The Knuckle is a tag-on design feature similar to those seen across Europe and in Singapore.

Sea Organ 2005, Nikola Basic, Zadar

Singapore water feature

- Cultural associations relating to accessing the water can be accommodated via the low seawall area at the Britomart Reserve which does not require steps, modifications or visual intrusions.

- If steps are deemed to be a cultural requirement then decking with steps down to the water's edge can be provided near Fisherman's Rest on the north side of the wharf to avoid congestion and potential conflict between the public and vehicles and equipment used by commercial operators.

General Comments

The Civic Trust is concerned that tangible links and heritage values relating to the historic Akaroa wharf have been largely erased rather than being conserved or acknowledged.

The Akaroa wharf is not primarily recreational in terms of its usage, therefore it cannot be compared to the New Brighton Pier which was constructed for recreational users.

The Akaroa Wharf is a highly active, commercial structure in every sense of the word and it could also become an economic lifeline in terms of coastal shipping and transport in the next 50-100 years.

The Knuckle is a visual addition which reflects popular design trends around the world that are created to attract tourists and visitors to congregate in a particular area.

The Knuckle has no historic relationship with, or precedence in, to either Akaroa or the South Island of Aotrearoa/New Zealand. The Knuckle will not connect people to a beach area because the shoreline on either side of the wharf is composed mostly of rock. Wave action on the southside of the wharf will impact the Knuckle as debris and rocks build up against it.

The Knuckle will create a demarcation between the area of the authentic, historic wharf to important landmarks and the heritage streetscape of the Britomart Reserve and Beach Road.

The height increase of the new abutment and wharf will make the Knuckle a dominating design feature. In our view it will have a long term negative visual impact on Akaroa's Historic Areas (NZHPT 7330 September 6, 1996; NZHPT 7443 February 5, 1999).

The visual impact of the contemporary Knuckle design feature will reduce the heritage values and amenity of the immediate heritage setting and historic streetscape.

In our view the Knuckle and aspects of the new wharf are contrary to the Design Guidelines for Akaroa, Origins Conservation Report and The ICOMOS New Zealand Charter 2010.

> The ICOMOS New Zealand Charter 2010 - The ICOMOS New Zealand Charter, Te Pumanawa o ICOMOS o Aotearoa Hei Tiaki I Nga Taonga Whenua Heke Iho o Nehe is a set of guidelines on cultural heritage conservation, produced by ICOMOS New Zealand.
>
> The NZ Charter is widely used in the New Zealand heritage sector and forms a recognised benchmark for conservation standards and practice. It is used by central government ministries and departments, by local bodies in district plans and heritage management, and by practitioners as guiding principles.
>
> Heritage New Zealand / Pouhere Taonga, the Ministry of Culture and Heritage and the Department of Conservation use the New Zealand Charter to guide their heritage conservation work. It was used by Ngai Tahu in their Deed of Settlement and the Lotteries Grants Board uses it for guidance in its deliberations.

The Charter has been adopted as heritage policy by a number of district councils and is used as a standard reference document in Auckland, Christchurch, Hutt City and a number of other local authorities.

The New Zealand Charter covers the purpose, principles, practice, and processes of conservation. It also provides useful definitions of the main conservation terms such as preservation, maintenance, restoration and so on.

- As the main wharf forms one of Akaroa's most significant cultural landscapes, the materials used to construct the new wharf should reflect, compliment and be in keeping with the historic character of the immediate area.

  Visual links and references between the old and new wharves should include the use of wood, similar railings and simple shapes for all buildings and benches.

  The surface of the wharf should remain timber as well as seating and detailing. The crane, owned by John Wright, should be retained as an historic feature.

  Bracing below the wharf continues a long established tradition as recommended in the Conservation Plan. Cross bracing provides visual continuity between the old and new structure.

  Colours should remain muted or dark to reflect the wood and character of the old wharf.

  The old wharf and abutment are highly textured but the sketches of the new abutment and wharf lack character, texture and colour.

  No further commercial development should to be allowed on the wharf itself; existing buildings should not be allowed to expand beyond their current footprint.

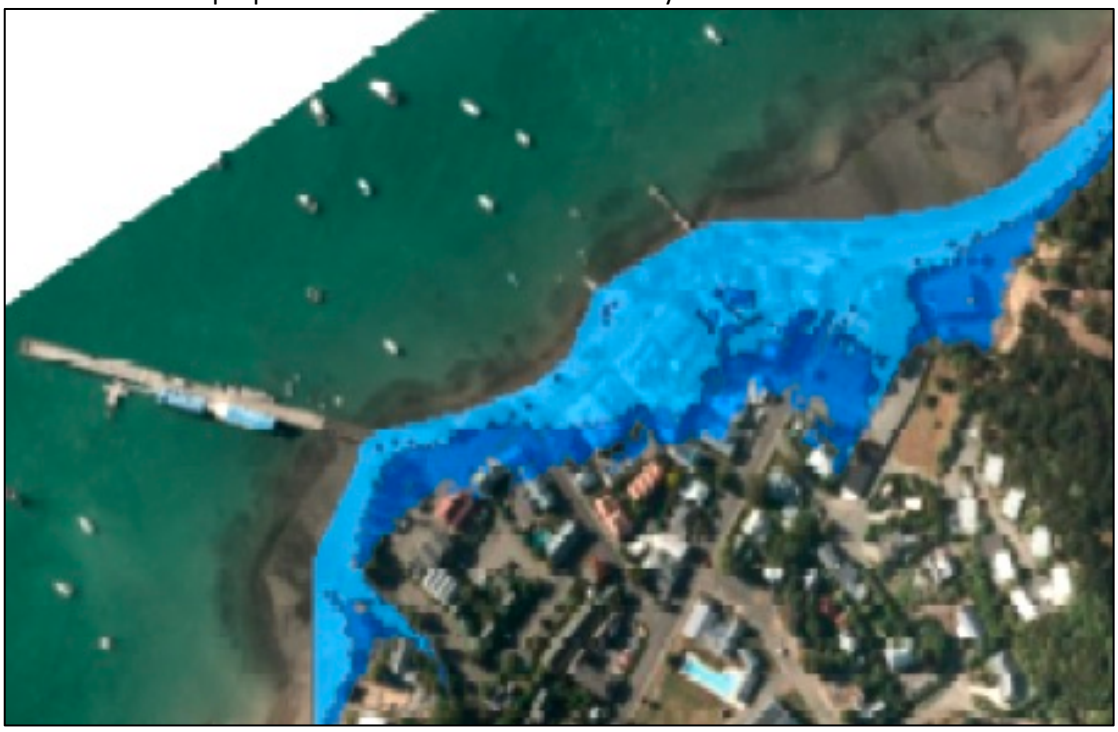
In Conclusion

The Council must needs to exercise regard for Akaroa's historic character and natural amenity with regard to the wharf's context, setting and streetscape. Akaroa has always been a bit "rough around the edges" as layers of time and history have washed over it. The revamped waterfront development along Beach Road in 2000 incorrectly sought to replicate the style of a seaside town along the French coast. The addition of hard, grey walls and limestone chip does not sit comfortably in the context of the historic streetscape.

Over the past twenty five years the desire on the part of Banks Peninsula District Council and Christchurch City Council for uniformity has gentrified the township. Generic street furniture (heritage off the shelf), makes the task of ordering easier for the council and the continued use of tactile pavers and imposition of new curbing imposes generic uniformity on the historic character and amenity of the original heritage fabric of the town.

Appendix A

The new wharf is proposed to last for between 50- 100 years.

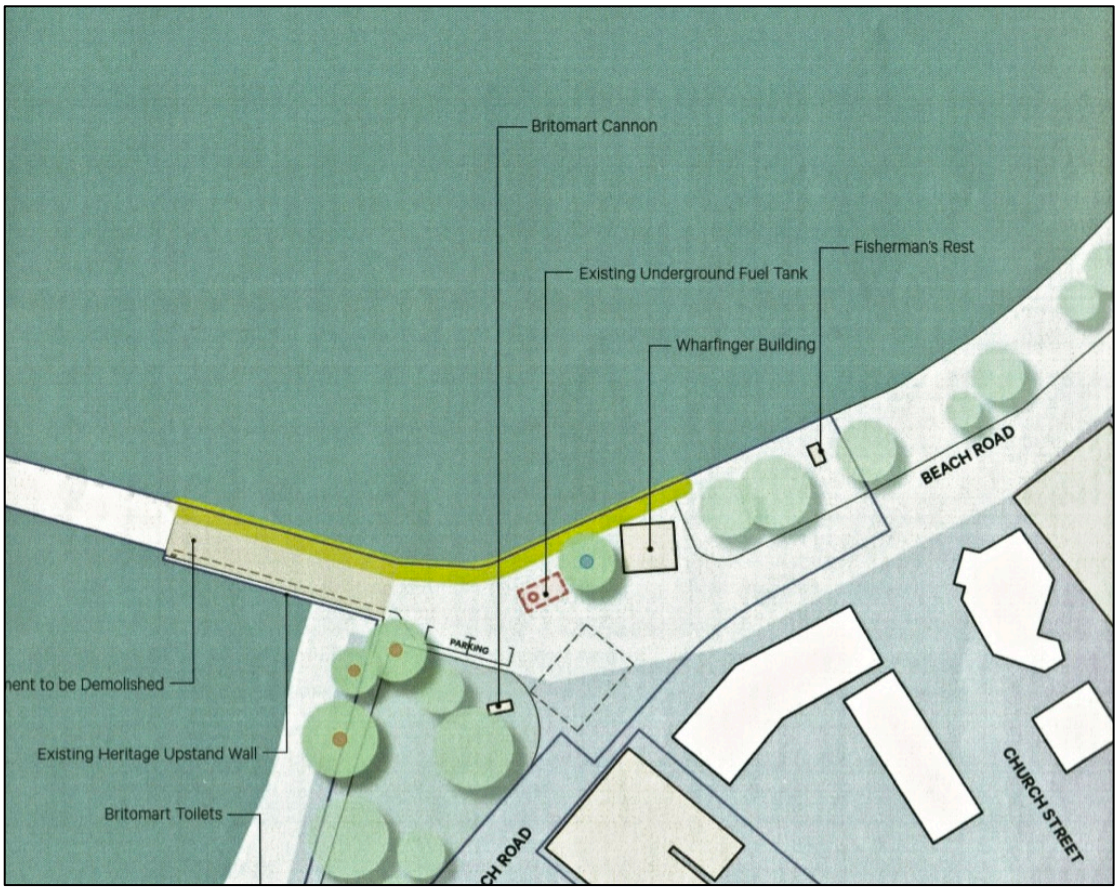


Tonkin and Taylor CCC Coastal Hazard Assessment Summary Report September 2021

Key Findings

Short Term: now to 2050; 0-20cm sea level rise

Long Term: 2100 and beyond; 1 to 1.5m sea level rise



According to the Akaroa Wharf Replacement Concept Design Feasibility Study, Isthmus September 6, 2021, the new wharf deck will be raised by 500 millimetres.

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Underwater noise levels of pile-driving in a New Zealand harbour, and the potential impacts on endangered Hector's dolphins

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ABSTRACT

Impact pile-driving generates loud underwater anthropogenic sounds, and is routinely conducted in harbours around the world. Surprisingly few studies of these sounds and their propagation are published in the primary literature. To partially redress this we studied pile-driving sounds in Lyttelton Harbour, New Zealand, during wharf reconstruction after earthquake damage. That Lyttelton harbour is routinely used by Hector's dolphins (*Cephalorhynchus hectori*), an endangered species found only in New Zealand, provided further context for this study. Steel piles of 0.61 or 0.71 m diameter were driven using three different pile-drivers. Maximum calculated source SEL was 192 dB re 1 μPa^{2}s @ 1 m (SPL_{0-p} of 213 dB re 1 μPa @ 1 m). Propagation of piling noise was strongly influenced by harbour bathymetry and a rock breakwater near the piling operation. We calculated range estimates at which Hector's dolphins may suffer temporary hearing threshold shift and behavioural change.

1. Introduction

Impact pile-driving produces impulsive, repetitive sounds that are among the loudest anthropogenic underwater sounds, particularly when steel piles are driven (Richardson et al., 2013). This form of noise pollution has been extensively studied in relation to windfarm construction (e.g. Bailey et al., 2010; De Jong and Ainslie, 2008; Nedwell et al., 2007) but there are very few studies of noise generated due to wharf construction that are published in the primary literature (for exceptions see Paiva et al., 2015; Würsig et al., 2000). Since several dolphin species routinely occur close inshore and in harbours (e.g. Dawson, 2018; Parra and Jefferson, 2018), this lack of literature is a potentially important weakness in the protection of these species.

Pile-driving noise has been established as a serious threat to some marine mammal species (Thompson et al., 2013). Wild harbour porpoise (*Phocoena phocoena*) show strong avoidance reactions to pile-driving (Brandt et al., 2011; Dähne et al., 2013; Tougaard et al., 2009). Temporary hearing loss has been documented in captive animals, following exposure to pile-driving noise (Kastelein et al., 2015). Hector's dolphin (*Cephalorhynchus hectori*), an endangered, nearshore delphinid found only in New Zealand, is routinely present in Lyttelton harbour. The Banks Peninsula Marine Mammal sanctuary (including Lyttelton harbour) was created in 1988 to reduce the impact of incidental catch in gill nets and trawling, the main threats to Hector's dolphins. That Hector's dolphins have very similar acoustic behaviour to harbour porpoises (Dawson, 2018; Dawson and Thorpe, 1990; Villadsgaard et al., 2007), are similarly sized and have broadly similar ecology (Würsig et al., 2018) raises the potential for pile-driving to be an additional impact, and provides the context for this study.

Impact pile-driving radiates noise into the water and sediment surrounding the pile. The majority of the underwater noise arises from radial expansion of the pile as it is struck by the hammer, radiating directly into the water column (Reinhall and Dahl, 2011; Tsouvalas and Metrikine, 2013). Energy is also transferred into the seabed, and can radiate back into the water, or travel as surface waves (Sholte waves) along the water-seabed interface (Tsouvalas and Metrikine, 2016a). For these reasons, pile-driving noise does not behave strictly as a "point" source. The spectrum of a typical pile strike is broadband, with most energy below 1 kHz but with significant energy extending to > 100 kHz, especially at close range (e.g. Nedwell et al., 2007; Tougaard et al., 2009).

Sound propagation is usually described as involving two kinds of losses, spreading losses and absorption. Spreading losses range between cylindrical (shallow water; 10*log(R), where R is range) and spherical (deep water; 20*log(R)). Absorption is frequency dependent, high frequencies are rapidly absorbed, while low frequencies can be detectable above ambient noise at very large ranges (Ainslie and McColm, 1998; Malme and Beranek, 1995). Shallow water, however, imposes a lower limit on the frequencies it can support to propagate based on depth (Forrest et al., 1993; Jensen et al., 2011). In practice, sound

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propagation is complex, especially in shallow water, influenced also by the roughness of the surface, depth, the nature of the bottom, and any layering in the water column (Marsh and Schulkin, 1962; Pine et al., 2014).

Modelling propagation from impact pile-driving presents an especially difficult challenge, due to the influence of bottom layer properties (Lippert and von Estorff, 2014) as well as bottom and surface reflections in shallow water transmission (Marsh and Schulkin, 1962). Currently there is no available software that can adequately model this complex process in a realistic coastal setting, accounting for the various environmental factors, and beyond ranges > 1.5 km (Denes et al., 2016; Duncan et al., 2010; Fricke and Rolfes, 2015; Reinhall and Dahl, 2011). For these reasons a strong empirical approach to measuring propagation was used in the present study.

The 2010 and 2011 Christchurch earthquakes extensively damaged the city's port in Lyttelton harbour. Port development was combined with repair work, under the Canterbury Earthquake Recovery Act (2011), allowing the work to be carried out without the usual resource consent process, and therefore, under less strict environmental management. The construction work involved 15 months of pile-driving.

Our purpose in this contribution is to describe the acoustic characteristics of noise pollution generated by impact pile-driving during the wharf reconstruction in Lyttelton harbour, quantify the propagation of this noise within this harbour, and investigate the potential impact this noise may have had on the local Hector's dolphin.

2. Materials & methods

2.1. Study area

Lyttelton harbour (43°36′47″S, 172°44′24″E), on the east coast of the south island of New Zealand, is a shallow harbour (Fig. 1) with a dredged shipping channel.

Pile-driving was carried out using three different impact hammers (Table 1). In each of these, hydraulic power was used to lift a steel hammer which then dropped via gravity on the top of the pile. The piles were steel, hollow, and closed-ended, with a diameter of 0.61 m or 0.71 m. Each pile was approximately 80 m long and driven an average of 66 m into the seabed (HEB construction, pers. comm. 2015). The contractor's records of pile-driving activity, which specified pile location, pile-driver, and the sequence of lift heights used, were made available by HEB construction and Port Lyttelton. A "soft start" using the hammer on its lowest energy setting for the first 2 min, was standard practice (i.e. required by the pile-driver manufacturers). Pile-driving was scheduled from Monday to Saturday between 7:30 am and 6 pm. Weather conditions restricted the actual operation time.

Table 1
Pile-drivers used in Lyttelton harbour.

Model	Gross weight (t)	Hammer weight (t)	Lift height range (m)	Max energy (kJ)
BSP 1146	35	14	0.5–1.5	206
Bruce SGH 1015	28	10	0.2–1.5	147
Junttan HHK18A	18	9	0.2–1.2	106

2.2. Field techniques and data collection

Sound recordings were made using three autonomous recorders (two DSG Ocean recorders and a SoundTrap HF) and two boat-based recorders (for recording locations see Fig. 1). The SoundTrap HF recorder (sampling frequency, f_s = 288 kHz, frequency response 20 Hz - 150 kHz ± 3 dB) was moored in an average water depth of 6.5 m, approximately 370 m from the piling activity ('SoundTrap' in Fig. 1). This location (close to the breakwater at 'Sticking Point') was chosen to reduce the risk of the recorder being damaged by docking vessels while minimising the range to the noise source. A DSG recorder (HTI-96 min hydrophone, f_s = 80 kHz, max. frequency response 2–30 kHz), was moored just outside the harbour channel, in about 8 m of water, directly in front of the piling 750 m away ('DSG' in Fig. 1). These two recorders were moored and removed each recording day. A further DSG recorder ('Duty cycle DSG' in Fig. 1) was set up on a duty cycle, recording for 5 min every hour (f_s = 80 kHz) and moored in about 9 m of water, continuously from February 27, 2015 to March 25, 2015, near a channel marker about 1.9 km from the piling activity. This recorder was used to record ambient noise. All autonomous recorders were moored about 2 m above the seafloor. Water height varied within 1.5 m due to tide (https://www.linz.govt.nz/). The substrate was generally a very fine clay silt mixture, including a small amount (1%) of sand, with a fluid mud layer on top (5–8 cm thickness, up to 45 cm in the channel), due to the high sedimentation in Lyttelton harbour (OCEL Consultants NZ Limited, 2014).

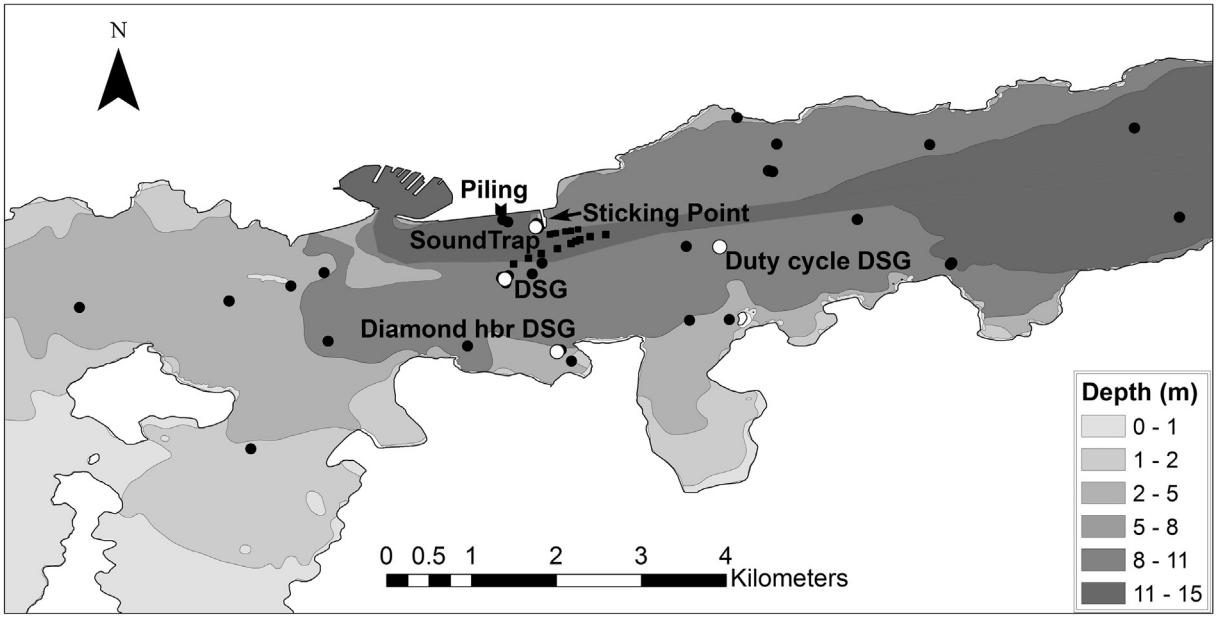

Fig. 1. Location of moored recorders (white dots) and boat based recordings (black dots) in Lyttelton Harbour.

Sound recordings were also made throughout the harbour at ranges of 92 m to 5.2 km from the piling, from an anchored or drifting 6.6 m research vessel (Fig. 1). For recordings beyond 400 m from the wharf, a sensitive, low-noise hydrophone specifically designed for measuring ambient noise (Reson 4032, Roland R-44 digital recorder, $f_s = 192$ kHz) was used.

To measure the broad spectrum of piling noise at close range (92–130 m) we used PAMGuard software running on a Laptop PC with a National Instruments 6351 A/D interface sampling at 500 kHz, with a Reson TC4013 hydrophone and VP2000 hydrophone amplifier. This hydrophone has a wider frequency response (20 Hz–170 kHz ± 3 dB) than the Reson 4032 (10 Hz–90 kHz ± 3 dB), and is better suited to recording very high signal levels due to its lower sensitivity.

Drift recordings enabled measurement of changes in pile-driving noise over small spatial scales, and were used to qualify the shadowing effect of Sticking Point. Distances from pile-driving were measured using a laser range finder (Leica Rangemaster 1000-R) and later compared to GPS locations recorded every 30 s on board the recording vessel.

All recording systems were routinely calibrated via a G.R.A.S. 42AA pistonphone (with appropriate couplers) with appropriate atmospheric corrections. All recordings were 16 bit. CTD (Seabird SB-19) casts were made at every recording location.

2.3. Sound analysis

Absolute sound levels were obtained using the pistonphone calibration tones on each recording. Calibration was carried out using the PAMGuide toolbox (from Merchant et al., 2015) in Matlab (Matlab 2014b, The Mathworks Inc.). The uncalibrated level a of the pistonphone tone at 250 Hz was determined using a power spectrum in PAMGuide (1 s Hanning window, 50% overlap). This was then compared to the known level b produced by the pistonphone (re 1 μPa: taking into account the effect of the couplers for each hydrophone) to produce a system sensitivity S:

$$S = b - a \quad (1)$$

S was then used as a correction factor for the corresponding recording.

Root mean square (RMS) broadband SPL is a useful metric to quantify an average level over a period of continuous noise (Merchant et al., 2015). An average level of ambient noise in Lyttelton harbour, was obtained close to the port, and at a location approximately in the centre of Lyttelton Harbour. Close to the port, we used recordings from the SoundTrap moored just inside Sticking point, and the DSG moored opposite the pile-driving (Fig. 1), gained on nine days between 4 January and 10 February 2015. From these recordings we calculated the overall RMS level for each day during the 30 min 'smoko' break in piling, and then took the median of those RMS values. In mid harbour, starting on 27 February, we used recordings from the duty-cycle DSG (Fig. 1), gained over a larger sample of days. For these recordings we calculated the RMS level over the entire record of 5 minute samples collected during the 26 day period it was moored in the harbour.

To analyse the noise from a particular pile-driver, hammer setting and pile location, a section which contained 10 strikes (as recommended by De Jong et al., 2011) was selected from the raw recording, avoiding flow noise, wave slap on the recording vessel and construction noise other than piling.

It has been shown that RMS level, a metric commonly used for measuring ambient noise, is not appropriate for transient signals such as a pile strikes (Madsen, 2005). The most widely used metrics for quantifying pile-driving noise are zero-to-peak Sound Pressure Level (SPL_{0-p}) and single-strike Sound Exposure Level (SEL), as defined in Southall et al. (2007). For transient signals, duration was defined as the '90% envelope' (T_{90}) (Madsen, 2005).

All measurements were made via a custom written script in Matlab. First the script applied the correction factor S and filtered the signal using a 30 Hz digital highpass filter. This removed most of the noise due to water flow past the hydrophone and wave slap from the vessel and had negligible effect on piling noise, which contained very little energy below 30 Hz. A peak-finding algorithm (Yoder, 2009) was applied to the filtered signal. Power spectral densities (PSDs) and third-octave-band levels (TOLs) were calculated (with 1 s inter-strike-intervals) using the PAMGuide toolbox (Merchant et al., 2015). A 1 s Hanning window was used with 50% overlap for TOLs and PSDs.

2.4. Propagation measurement and modelling

Our aim was to create a strong empirical base of measurements from many locations throughout the harbour, using a simple propagation model to interpolate between measurement locations, and to extrapolate beyond them. A model is needed because it is difficult to construct a noise map only from measurements, as it is unrealistic to make recordings at all map locations in time short enough that none of the above variables change (De Jong et al., 2011). We aimed to find a propagation model that was as simple as possible while being sufficiently adaptable to represent important influences on the harbour's soundscape.

Statistical modelling (using general linear models) was used to determine which factors ('energy' - hammer energy (kJ); 'pile driver'; (Bruce, BSP or Junttan); 'stage', stage of pile-driving (start, end or setting of pile); 'row', pile row on wharf (A–F); pile diameter (0.61 or 0.71 m); 'pile ID'; 'day', date of recording) significantly influenced the received level of pile-driving noise, using recordings from the DSG location (Fig. 1). The best fitting model was determined by comparing AICc scores and using ANOVA (stats package, R Development Core Team, 2006) to test the significance of each term. Results were used to determine a subset of data representing the largest collection of recordings made under similar conditions. These were used for modelling propagation.

Measurements were made over an average of 10 strikes for the stationary recordings, and over single strikes for the drifting recordings (because range was changing). The latter data were weighted at 1/10th of the averaged measurements in the fitting procedure.

We assumed that bottom layer properties and sea surface roughness were constant over the data gathering period. Boat-based recordings were restricted to wind conditions below Beaufort 3, a wind range having negligible effect on sound transmission loss (Norton and Novarini, 1996) to at least 4000 m from the noise source.

In harbours, absorption, spreading losses, effects of depth, and bottom hardness can all contribute to propagation loss. Considering that most of the energy in pile strikes is at < 1 kHz, absorption has little effect (< 1 dB; Ainslie and McColm, 1998) on the broadband sound level over the ranges in this study (< 4 km), and spreading losses will be much more important. The shallow depth of much of the harbour strongly restricts propagation of low frequencies. The lower cut-off frequency for water of 6 m deep (over a sandy-silt bottom layer) is approximately 2000 Hz (Jensen et al., 2011; Shumway, 1960), meaning that little of the acoustic energy present in pile strikes was likely to propagate into the inner harbour. Additionally, the soft bottom layer gives poor reflection of the sound waves as they travel through the harbour leading to increasing loss with range (Jensen et al., 2011). Hence, the $-bR$ term (below) allows the model to reflect these losses as an effect that increases with range.

A model with source level (SL), geometric spreading coefficient (a) and absorption loss coefficient (b) was fitted to the dataset:

$$RL = SL - a\log_{10}(R) - bR \quad (2)$$

where RL is the received level (in dB re 1 $\mu Pa^2 s$) at range R (in meters) (Urick, 1983). Note that while absorption is heavily dependent on frequency, the absorption loss coefficient, b, in the propagation model (in dBm^{-1}) includes absorption across the entire frequency range of the

pile-driving noise, not just a single frequency.

2.5. Noise map

Because source levels of pile strikes varied with pile-driver, pile location, substrate, penetration depth and hammer lift, we show propagation as a contour map of losses instead of absolute sound pressure levels. The fitted propagation model was used to generate a grid of 'loss with range' points spaced 0.005° in both latitude and longitude. Using the grid of losses enabled smooth interpolation between all recording locations. The grid was adjusted to integrate results of recording locations where there was no detectable change in pressure between ambient and piling noise in the waveform. In these cases it was often still possible to hear the pile-driving in the recording. To determine what propagation loss would be required for the piling noise be indistinguishable from ambient noise, the average ambient broadband SPL was compared to the average pile-driving source SPL_{0-p}. While there is no exact way to compare these rather different noise measures, this approach most accurately represents the decibel difference between the peak levels of pile-driving noise and the average ambient noise. This level was obtained by first determining an average level for the ambient broadband SPL. The overall average of the source SPL_{0-p} was derived by converting the modelled source SEL using the linear relationship between the measured data for these metrics.

Interpolation between loss points was calculated in ArcGIS (v10.3) using the local polynomial technique (with settings: polynomial order 2, smoothing factor 0.2 and an exponential kernel). To give more weight to the empirical measurements, the levels measured from point (averaged over 10 strikes) and drift recordings were weighted 100× and 10× higher, respectively, than the modelled grid points. The contours were drawn at 6 dB loss intervals, representing successive halving of sound pressure.

2.6. Impact zones

Recordings throughout the harbour were used to estimate ranges of Temporary Threshold Shift (TTS) onset. These estimates were based on previous studies of TTS in harbour porpoise. The "equal energy rule" is a useful concept as it includes both effects of noise amplitude and duration on TTS (Finneran, 2015). TTS onset in harbour porpoise, although dependent on a combination of duration and peak sound pressure levels of the noise, does not follow this rule (Mooney et al., 2009). Additionally, it is well known that the equal energy rule overestimates TTS for intermittent noise (Finneran, 2015). Hence, different ranges of impact are estimated based on different types of noise exposure. The relevant results used were: (1) TTS induced in a trained harbour porpoise after exposure to a single airgun pulse with an SEL of 164 dB re 1 μPa^2s (Lucke et al., 2009); (2) TTS induced in a trained harbour porpoise after exposure to 1 h of played-back pile-driving noise (2760 strikes with an inter-pulse-interval of 1.3 s, with single-strike SEL of 146 dB re 1 μPa^2s; Kastelein et al., 2015); (3) a trained harbour porpoise exposed to a playback of pile-driving noise in a pool began to change its behaviour once the single strike SEL reached 133 dB re 1 μPa^2s (Kastelein et al., 2013a; this threshold was estimated to be similar to what was observed in studies of wild harbour porpoise, Tougaard et al., 2009; Brandt et al., 2011; Bailey et al., 2010; Dähne et al., 2013) and (4) the maximum threshold level for detection of pile-driving noise in a trained harbour porpoise in a quiet pool was at a single-strike SEL of 75 dB re 1 μPa^2s (Kastelein et al., 2013b).

3. Results

All platforms combined recorded a total of 147.5 h of underwater sound, of which 52 h were from the duty cycle DSG, 16.3 h were made on board the research vessel, and the remaining from the stationary DSG and SoundTrap. CTD casts made during the boat-based recordings indicated a well-mixed water column with a mean temperature of 19.0 °C (17.1–20.0 °C), and mean salinity of 34.1 PSU (33.3–34.3 PSU).

3.1. Ambient noise

Ambient noise levels measured over 26 days using the duty cycle DSG had a peak frequency around 300 Hz with a median PSD level around 60 dB re 1 $\mu Pa^2\,Hz^{-1}$. The RMS broadband level over this period was 117.9 dB re 1 µPa, with 50% and 95% exceedence levels at 101.8 and 108.9 dB re 1 µPa, respectively. Recordings made during breaks in pile-driving showed highly variable broadband levels (96–146 dB re 1 µPa), and generally had most energy below 5 kHz. Median RMS broadband levels across this period were 119.2 dB re 1 µPa for the SoundTrap (50% and 95% exceedence levels at 112.4 and 101.1 dB re 1 µPa, respectively) and 119.6 dB re 1 µPa for the DSG (50% and 95% exceedence levels at 111.6 and 100.7 dB re 1 µPa, respectively) (average = 119.4 dB re 1 µPa).

3.2. Pile-driving noise

Over 92 days, pile-driving occurred on 46 days, with an average of 125.5 min of piling per day (SE = 16.7 min).

Recordings made at close range (up to 370 m) show strikes with high peak-to-peak SPLs and steep rise times (Fig. 2). The strikes are broadband with most energy present below 1 kHz, though some energy extends beyond 100 kHz (Fig. 3).

The maximum recorded level (averaging 10 strikes) had an SEL of 158 dB re 1 μPa^2s and an SPL_{0-p} of 182 dB re 1 µPa at 370 m from the source. The fitted propagation model (see below) suggests that this would correspond to a point source SPL_{0-p} of 213 dB re 1 µPa @ 1 m.

All three drivers produced a similar distribution of energy across the frequency range: the highest energy was around 200–300 Hz, most energy contained between 50 Hz-10 kHz, but there was some energy to at least 100 kHz, particularly for the Bruce (Fig. 3).

Strike duration (T_{90}) varied between 59 and 624 ms. The longest durations occurred when the hammer was bouncing (Fig. 4), at the end of a piling sequence. Pile-driving stopped when pile movement was < 2.5 mm/blow on full power (D. Smith, HEB project engineer, pers. comm.). At this point the pile is considered to have hit solid substrate, and the elasticity of the pile causes the hammer to bounce. This produced the smaller secondary impulse closely following the main strike.

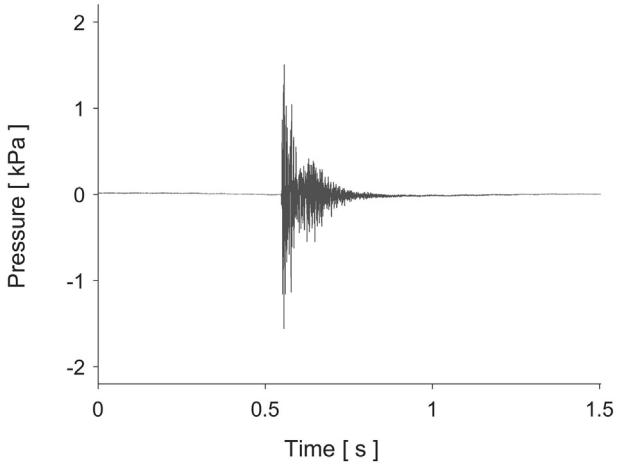

Fig. 2. Pressure waveform of pile strike, made by 'Bruce' hammer, recorded at 97 m from the pile-driving, frequency range 30 Hz–250 kHz (sampling rate 500 kHz).

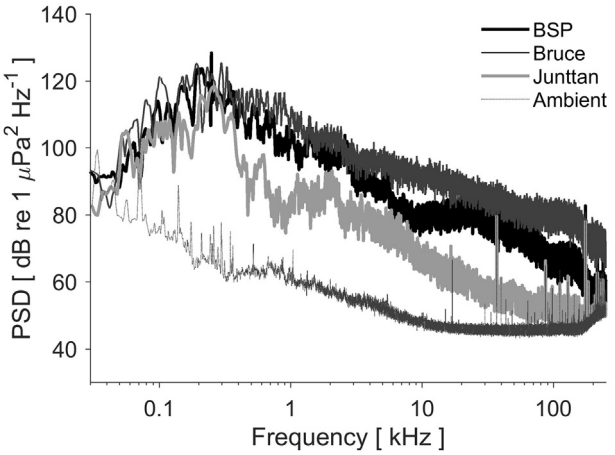

Fig. 3. Power spectral densities of all pile drivers and ambient noise, recorded at c. 100 m from the pile-driving, frequency range 30 Hz–250 kHz (sampling rate 500 kHz).

3.3. Statistical modelling

The formula of the GLM with the lowest AICc score, containing only significant terms (Table 2), was:

$$SEL \sim energy^{*}pile\ driver + stage \quad (3)$$

The '*' indicates an interaction between the variables energy and pile-driver. It was concluded from this model that row, diameter, pile ID and day did not significantly influence the received SEL.

The subset of data used for the propagation modelling, therefore, included only recordings made from the Bruce or BSP hammer at the end stage of piling, at lift heights above 1.1 m. Since pile diameter was not a significant influence on the sound level here, the subset contained recordings from both pile sizes.

3.4. Propagation modelling

The measured pile-driving SEL decreased approximately logarithmically with distance (Fig. 5). The values obtained for the fitting parameters (Table 3) do not necessarily represent the physical properties in Urick (1983). In our case they are the simply the best fitting parameters to describe the combination of all the influences on transmission loss, not only geometric spreading and absorption in the water. It should be noted that while Eq. (2) could be fitted to pile-driving noise measurements in other scenarios, the fitted parameters apply only to the conditions in Lyttelton harbour, for the pile diameters and hammers described above.

Table 2
Parametric coefficients of terms in Eq. (3) fitted to pile-driving data using a GLM in R.

Parametric coefficients	Estimate	(95% confidence interval)	p-Value
Intercept	139.3	(138.2, 140.4)	$< 2*10^{-16}$
Energy (scaled), kJ	0.055	(0.036, 0.075)	$2.16*10^{-16}$
Stage: setting	−2.812	(−2.425, 1.180)	0.0191
Stage: start	4.996	(−10.790, −3.288)	0.0002
Pile driver: Bruce	−0.622	(−5.061, −0.564)	0.5029
Pile driver: Junttan	−7.039	(2.606, 7.386)	0.0007
Energy * Bruce	−0.002	(−0.038, 0.033)	0.8855
Energy * Junttan	0.116	(0.057, 0.174)	0.0004

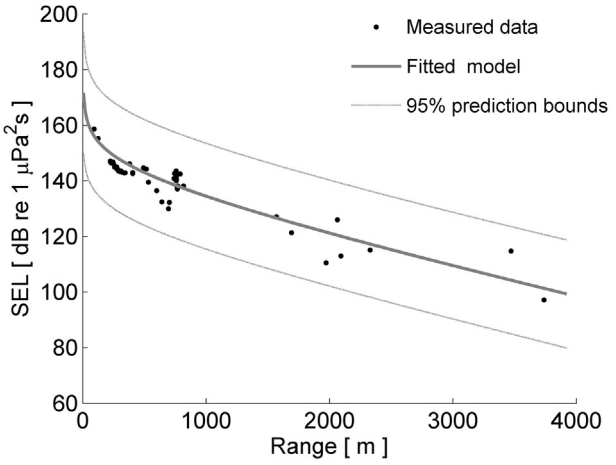

Fig. 5. Propagation model fitted with source level and the spreading and absorption loss coefficients as fitting parameters (adj. R^2 0.86).

Table 3
Fitted parameter values for propagation model (Eq. (2)) calculated using Matlab. Adjusted R^2 was 0.86.

Parameter	Predicted value (95% confidence bounds)
Source level	182 (167, 197) dB re 1 μPa²s
a	12.6 (6.65, 18.6) dB
b	0.0095 (0.0071, 0.0118) dBm^{-1}

3.5. Noise map

A strike's SPL_{0-p} appeared to increase linearly with SEL, with the fitted relationship:

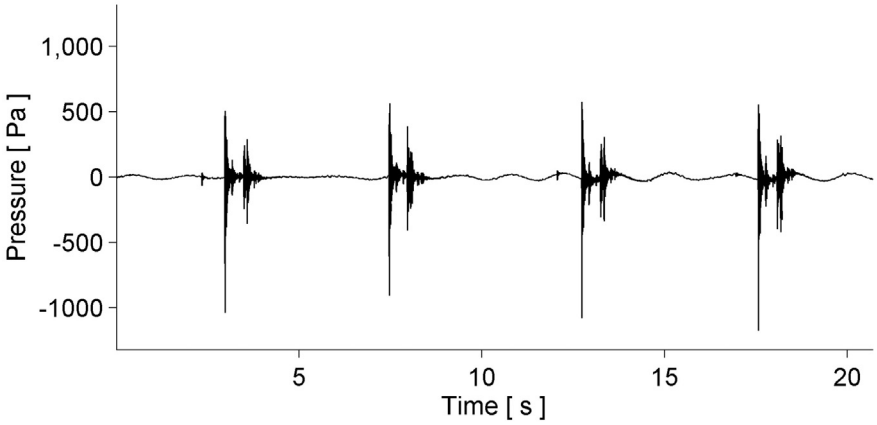

Fig. 4. Pressure waveform of BSP bouncing, end stage, lift height 1.5 m, on Jan. 27, 2015, frequency range 30 Hz–250 kHz, range to piling 103 m.

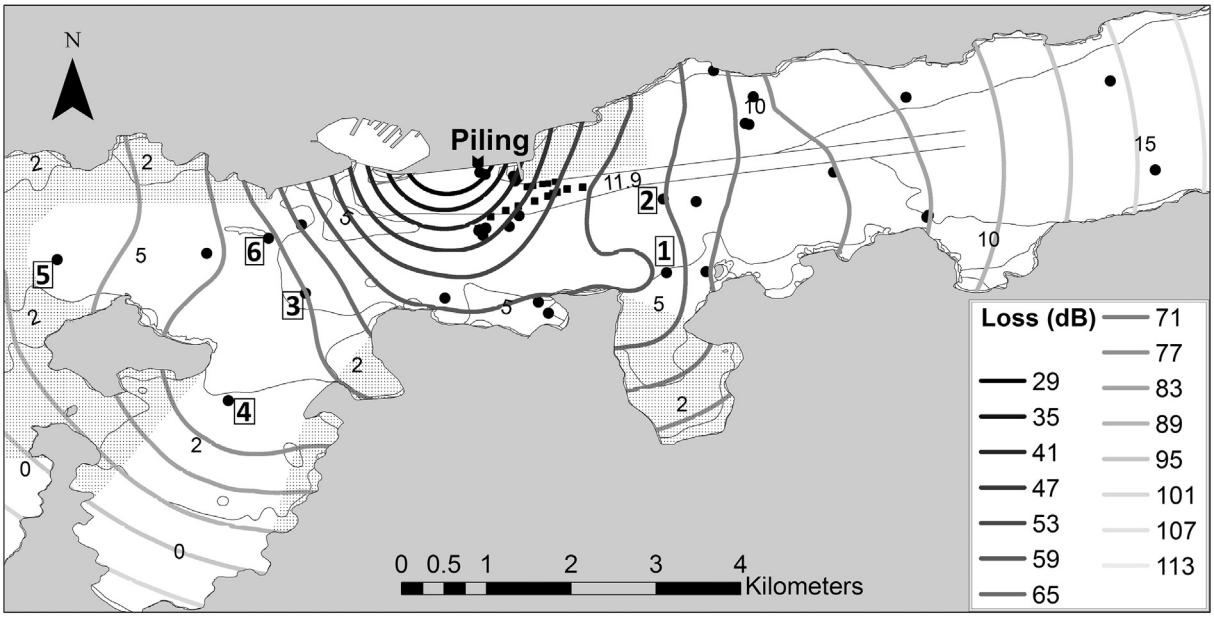

Fig. 6. Transmission loss contours in dB (thick, grayscale lines) are plotted over the harbour bathymetry (white fields numbered with maximum depth in m). Recording locations are indicated as black dots. The stippled areas indicate where the loss contours are likely unrealistic based on the fact that shielding will greatly increase the loss at these locations. Boxed numbers label specific recording locations for reference.

$$SPL_{0-p} = 0.95 \times SEL + 29.62, (R^2 = 0.95) \quad (4)$$

Using Eq. (4), a fitted source SEL of 182 dB re 1 μPa^{2}s corresponds to a source SPL_{0-p} of 202.4 dB re 1 μPa. This is effectively what the average source SPL_{0-p} of the Bruce or BSP driver would be, in the end stage of piling, if it behaved as a point source of sound. The difference between this and the average broadband RMS noise level (close to the port) is 202.4–119.4 = 83.0 dB. Modelled losses at grid points beyond where piling noise was measured to be indistinguishable from ambient noise were adjusted if necessary. If the loss at these points was < 83 dB, indicating underestimation of loss by the model, the loss value was increased to 83 dB.

The non-circular contours (Fig. 6) indicate that the soundscape is strongly influenced by factors other than range. The most notable feature is the lower transmission loss towards location 1 compared to those shielded by Sticking Point (the breakwater to the east of the piling, see Fig. 1), for example location 2. The other interesting pattern on the western side is the large spacing in contours between locations 3 and 4. A possible explanation for this relatively low loss with range could be the shallowness of the water in this area, leading to cylindrical rather than spherical spreading.

Piling noise is very broadband at close range (Fig. 7a). Further away, both piling and ambient noise levels decrease. The recording at (b) was shielded by Sticking Point, which appears to have blocked most of the higher frequencies (> 1 kHz) from propagating further (Fig. 7b). At location (c), almost 4 km away and in very shallow water, only the high frequencies persisted (Fig. 7c).

A breakwater (Sticking Point) present near the piling strongly influenced the propagation of the pile-driving sound (Fig. 8). SEL suddenly decreased as the drifting recording vessel passed Sticking Point (c. 526 m mark, Fig. 8), indicating a significant shielding effect.

3.6. Estimated zones of impact

3.6.1. TTS from a single pile-driving strike

Using a source level of 182 dB re 1 μPa^{2}s, our propagation data (Fig. 5) imply that an SEL of 164 dB (the level which induced TTS in a harbour porpoise after exposure to a single airgun pulse; Lucke et al., 2009) would occur in Lyttelton at a range of about 26 m from the pile-

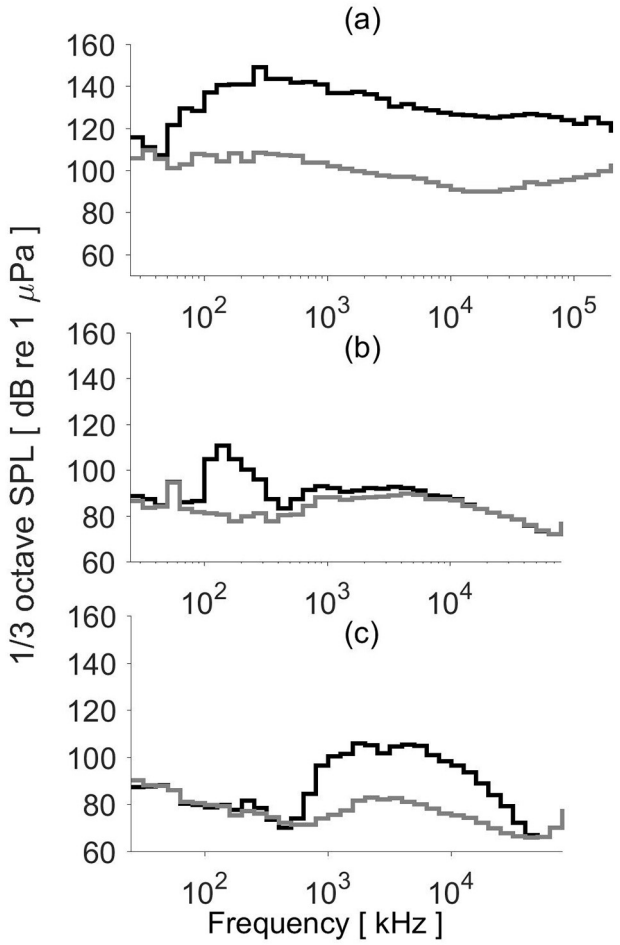

Fig. 7. Piling noise TOLs (black line) and ambient noise TOLs (grey line) measured at three locations around the harbour. (a): 100 m from piling, water depth 12 m; (b): at location 2 in Fig. 6, water depth 8 m, (c): at location 4, water depth 3 m.

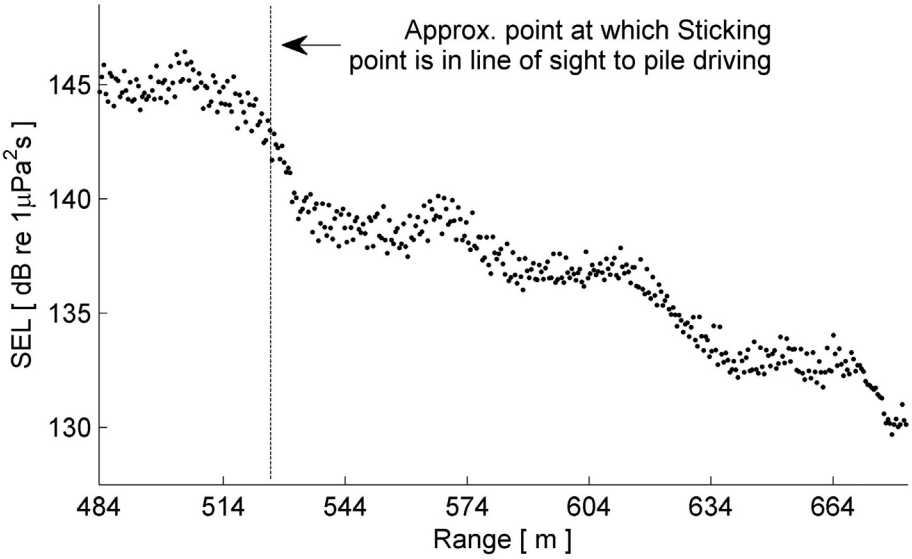

Fig. 8. SEL of each strike recorded while drifting past Sticking Point over a period of 11 min. Approximate range at which breakwater starts shielding pile-driving sound from the boat-based recording system is indicated by the vertical dotted line (526 m). Frequency range 30 Hz–96 kHz.

driving. Since this range is well within the near field of the pile-driving noise, it may not be reliably estimated. Because the hearing thresholds in that particular porpoise were considered to have been elevated (Lucke et al., 2009), this level should be considered a masked TTS. Hence, the range estimated at which TTS may occur in Hector's dolphin (with normal hearing thresholds) may be an underestimate.

3.6.2. TTS from 1 h of exposure

An SEL of 146 dB re 1 µPa²s (the single-strike level of pile-driving noise which induced a TTS in a harbour porpoise after 1 h of cumulative exposure; Kastelein et al., 2015) would occur at a range of about 376 m from the pile-driving. Using the map of loss contours (Fig. 6) this would occur at the loss contour of 36 dB and cover an area of approximately 0.38 km² (Fig. 9). The mean time between strikes was 1.3 s in the present study, but longer intervals (up to 4.5 s) were observed, particularly at the higher hammer lift-height settings (producing generally louder pile-driving noise). Since cumulative sound exposure level depends on the individual strike's SEL and the number of exposures (Southall et al., 2007), longer inter-strike-interval would require a longer period of exposure before inducing the same TTS.

3.6.3. Behavioural change

A captive harbour porpoise changed its behaviour when pile-driving noise was replayed at an SEL of 133 dB re 1 µPa²s (Kastelein et al., 2013a). In Lyttelton, this level would occur at a range of about 1120 m and at the loss contour of 49 dB (Fig. 9). Detection levels are, not surprisingly, much lower. A harbour porpoise could detect pile-driving noise in a quiet pool at an SEL of 75 dB re 1 µPa²s (Kastelein et al., 2013b). In Lyttelton this would occur at the 107 dB loss contour, well beyond the loss of 83 dB required for the pile-driving noise to be at the level of the average ambient noise. For the 5% most quiet times (in terms of ambient noise) in Lyttelton the pile-driving noise would then

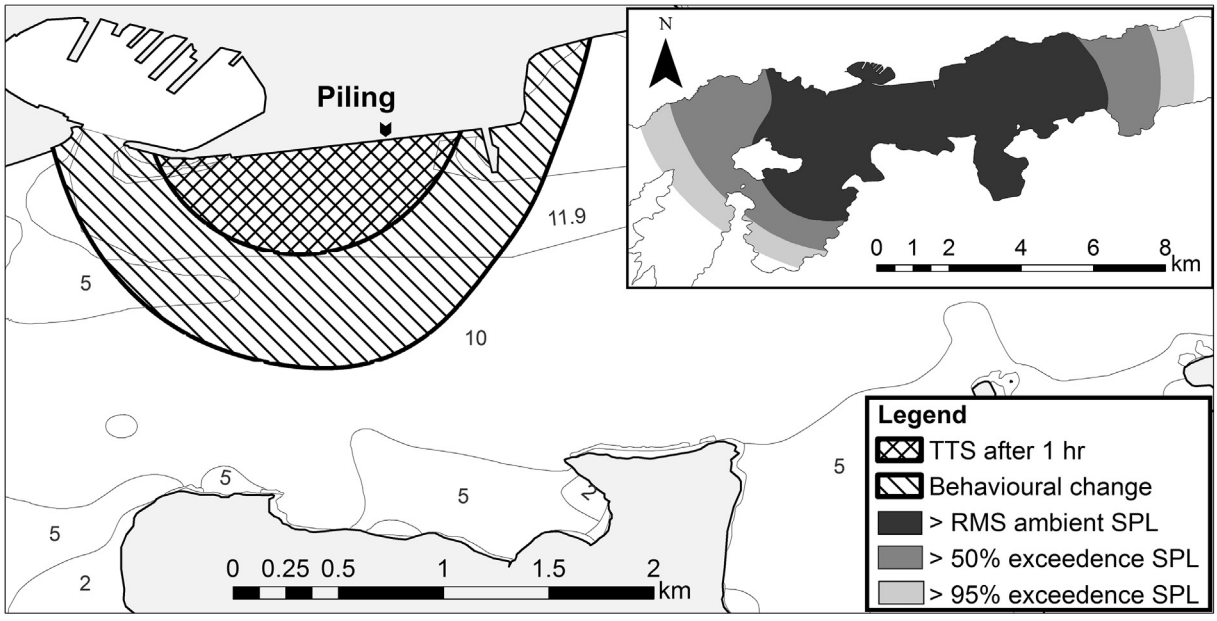

Fig. 9. Approximate zones in which pile-driving sound could impact Hector's dolphins. Inset: Increasingly lighter grey areas where pile-driving noise normally exceeds the RMS, 50% exceedence and 95% exceedence ambient noise levels, respectively.

be detected in an area up to 33 km^2 (see inset Fig. 9). However, for most of the time the ambient noise level is much higher, which will act to mask pile-driving noise and decrease the range over which pile-driving is detectable.

4. Discussion

Pile-driving introduced a large amount of noise into an already noisy harbour environment. Peak pressure levels were raised by over 1000 Pa (180 dB) (Figs. 2 & 4). At close range TOLs were raised by up to 45 dB across a wide frequency range (Fig. 7a), exceeding background levels 50% of the time over an area of up to 28 km^2.

There are surprisingly few peer-reviewed, published studies examining pile-driving in the context of wharf construction in harbours. An extensive set of measurements have been reported by the California department of transportation (Buehler et al., 2015), from many pile-driving projects, including a range of pile types and diameters. Most measurements were made in the near field and, therefore, are not directly comparable to our data from Lyttelton harbour (since measurements were only carried out in the far field). However, the SEL of 157 dB re 1 μPa^2s measured at 158 m, in water depth of 4 m, during bridge construction using 0.61 m diameter piles (no information on substrate or hammer energy), was similar to the modelled SEL of 153 dB re 1 μPa^2s at the same range in Lyttelton. The SELs at ranges of 260–340 m and 853–1530 m, in 0.9–9.1 m water depth, measured during wharf construction using 0.61 m diameter piles, were within 1 dB of the modelled levels in Lyttelton at these ranges. A more distant measurement at 2820–2922 m (SEL of 126 dB re 1 μPa^2s), was 15 dB higher than the modelled level in Lyttelton at this range, indicating that the transmission loss at this range was higher for Lyttelton. This is confirmed by the high absorption loss coefficient (Table 3), which is most significant at larger ranges.

Duncan et al. (2010) measured pile-driving noise in Port Phillip Bay, Australia, under very similar conditions to the pile-driving in Lyttelton. Pile type (diameter and material), hammer energy, and water depth were comparable to those in our study. The substrates in Duncan's study were silt layer on sand or sand on calcarenite, both layer types are much harder, with higher densities, than the mud/sand layer in Lyttelton. Comparing SELs at the same range from pile-driving shows that the levels measured in Lyttelton were lower by about 12 dB (Duncan et al., 2010). While the frequency content of pile-driving is relatively similar for most studies, the sound pressure levels recorded in this study are much lower than those of previous studies. Most studied much larger pile diameters, such as those used in offshore wind farms (for example Nedwell et al., 2007; Tougaard et al., 2009; Brandt et al., 2011), harder substrates (for example Nedwell et al., 2007; Robinson et al., 2007; Tougaard et al., 2009) and/or higher hammer energy (for example Lepper et al., 2009; Bailey et al., 2010; Brandt et al., 2011). Most studies were in much deeper water. Lyttelton Harbour is generally shallow; charted depths range from c. 13 m at the entrance to c. 5 m in front of the port, with an 11.9 m deep dredged channel allowing access for shipping. Our shallowest recordings were made in about 3 m of water. The shallowness of the harbour contributes to greater propagation loss for low frequencies.

The most comparable levels were recorded in the inner harbour of Fremantle, Australia (Paiva et al., 2015) where the SEL at 54 m was within 1 dB of our modelled level at this range. No information was available on hammer energy or pile diameter but since this harbour also experiences siltation (Paiva et al., 2015) the top layer of substrate is likely to be similar to the fluid mud layer in Lyttelton.

4.1. Propagation modelling

One of the more sophisticated attempts at modelling propagation of pile-driving noise in a harbour using freely available software (AcTUP v2.2L toolbox for Matlab; Collins & Porter, 2005; theory from Jensen et al., 2011), is by Duncan et al. (2010). This model considers spreading and absorption loss as well as influences of bathymetry and bottom layer properties. We attempted this modelling approach, and that of Marsh and Schulkin (1962), but the limited knowledge of Lyttelton's bottom layer properties and the model's high sensitivity to these inputs restricted the value of model outputs. Another approach, by Denes et al. (2016) used the parabolic equation method, but the model was validated at only two measurement locations and was likely inaccurate for ranges beyond those (> 1 km). Our approach was instead to develop a simple propagation model based on as much data as possible, referenced to measured pressure levels from multiple locations. The empirical data were weighted heavily in producing a contour map of losses (Fig. 6). The result is that the point recordings act to define the pressure levels, while the model interpolates between, and beyond them.

The geometric spreading coefficient of 12.6 was closer to cylindrical propagation (10) than to spherical propagation (20), most likely due to the shallow water depths in Lyttelton (3–13 m). Studies in deeper water show spreading losses of 20 (Bailey et al., 2010), 17–21 (Nedwell et al., 2007) and 16–29 (Blackwell, 2005). The absorption loss coefficient found in Lyttelton (0.0095 dBm^{-1}) is much higher than found in these studies, most likely due to a combination of higher absorptiveness of the soft bottom layers in Lyttelton and the shallower water depths in the harbour.

The noise map (Fig. 6) visualises how piling noise spread throughout the harbour. We think that this is an approach that should be used more. Further pile-driving is proposed in a planned expansion of the port of Lyttelton; this map provides useful information on how those sounds are likely to propagate. The contours, however, are approximations influenced by bottom layer properties, bathymetry and frequency content of the signal. Contour maps of underwater noise have been produced in previous studies (see for example (Cobo et al., 2007; Rossington et al., 2013) but to our knowledge none are based on the combination of modelled and empirical measurements. The map could be used for similar sources of anthropogenic sound near the wharf, so long as the source level is known, to estimate what sound levels would be received in different parts of the harbour. In particular, future studies of dolphin habitat use in Lyttelton Harbour may identify specific areas that are important (e.g. for foraging), in which the received noise level could be estimated. The accuracy of estimated levels will depend on how similar the frequency spectrum of the source is to the pile-driving noise used to develop the model.

4.2. Impact on Hector's dolphins

Hector's dolphins in Lyttelton harbour are routinely exposed to anthropogenic noise, particularly from small and large vessel traffic. Pile-driving noise had a much higher peak pressure, was impulsive, and was present for around 2 h (but up to 9 h) per day. It had the potential to impact Hector's dolphins in a variety of ways. If sufficiently close to the piling, Hector's dolphins could experience temporary hearing loss (Fig. 9), which could decrease their ability to forage via echolocation and detect environmental cues. It must be noted that the original recording of the pile-driving used in the playback in Kastelein et al. (2015) was made with a sampling frequency of 65 kHz therefore contained no frequencies above 32.5 kHz. Harbour porpoise hearing, however, reaches maximum sensitivity around 130 kHz (Kastelein et al., 2002) – frequencies that are certainly present in pile-driving strikes recorded at close range (e.g. Fig. 3; also see Dyndo et al., 2015 and Hermannsen et al., 2014 for impacts of low levels of high frequency noise on harbour porpoise). Also, Kastelein et al. (2015) replayed pile-driving sounds to a captive harbour porpoise at only one level (146 dB SEL re 1 μPa^2s), which was as loud as their equipment could produce, and found that this level caused TTS. It is possible that a lower level would have caused TTS also. It is important that 146 dB SEL re 1 μPa^2s is not to be regarded as the threshold at which TTS was induced.

The level at which TTS is induced also depends on the frequency of

the sound, with a lower threshold for higher frequency sounds, following the harbour porpoise audiogram (Tougaard et al., 2015). Furthermore, this TTS was measured in one captive harbour porpoise, which may have a lower hearing sensitivity than wild harbour porpoise. The level found to induce TTS in Kastelein et al. (2015), therefore, is likely to underestimate the level at which TTS would occur in response to actual (as opposed to recorded then played back) pile-driving noise on wild harbour porpoise.

Pile-driving noise is unlikely to mask echolocation clicks, but has much more masking potential for environmental cues (e.g., from prey and predators) as these are at a much lower frequency than echolocation clicks, and pile-driving noise has much more energy in these frequency ranges.

Although reporting the details is beyond the scope of this paper, we made visual and acoustic observations which are relevant to the question of how dolphins responded to pile-driving sounds. Of 15 boat surveys in Lyttelton Harbour during this study, Hector's dolphins were seen on 13. Seven sightings were made within 500 m of the piling location, three of which were within 3–7 min of piling activity. On 10 days our SoundTrap HF recorder was moored inside Sticking Point, approximately 370 m from the piling location. Hector's dolphin sonar clicks were clearly evident in recordings made on eight of those 10 days. On five days dolphin clicks were recorded simultaneously with pile-driving strikes. Our experience suggests that to be recorded at all, dolphins would have had to be within c.200 m of the recorder. Taken together, these observations indicate that pile-driving did not prevent at least some Hector's dolphins from using the nearby area (i.e. within some hundreds of meters of the pile-driving).

We also had three echolocation detectors (v.5 T-PODs) moored in the inner, middle and outer harbour. Statistical modelling of dolphin detections during pile-driving showed a significant decrease in the inner harbour, closest to the pile-driving activity, with a concomitant increase in detections in mid harbour (which is shielded by Sticking Point). This is consistent with dolphins moving away from the area closest to the piling operations into quieter areas (Leunissen, 2017). These data indicate that pile-driving acted to reduce the foraging area available to the dolphins. If displaced far enough out of the harbour, risk of being caught in fishing nets could be increased (Forney et al., 2017).

Because the pile drivers in this study were much smaller than those used in construction of offshore windfarms, our estimated areas of audibility (33 km^2) and behavioural change (1.5 km^2) are much smaller than those measured for harbour porpoise in relation to offshore windfarms (e.g. c.15,000 and 1400 km^2 respectively; Bailey et al., 2010). Hector's dolphin is an inshore species, with individuals having very small home ranges (Rayment et al., 2009). The pile-driving occurred within a confined harbour environment. Together these features increase the likelihood that this pile-driving operation may have had a significant impact on the local Hector's dolphins.

NOAA and NMFS (2016) have recently provided recommendations on permanent threshold shift (PTS) and TTS thresholds for cetaceans classified as having low, mid and high frequency hearing. These thresholds are based on frequency weighting noise according to the inverse audiogram of representative species in each frequency group (Finneran, 2015). Based on the worst case scenario in Lyttelton (i.e. max. single-strike source SEL of 192 dB re 1 μPa^2s, 2700 strikes per hour, 9 h of piling per day) the 24-hour cumulative PTS onset isopleth would occur for Hector's dolphins at c. 1500 m from piling, and for TTS at 2700 m (average 440 m and 1400 m, respectively, based on single-strike source SEL of 182 dB re 1 μPa^2s, 2700 strikes per hour, with 2 h of piling per day).

While the proposed thresholds represent the current best science, there are issues that need to be addressed. The thresholds of impulsive sound for the high-frequency cetacean group (including Cephalorhyncids) are heavily based on the Kastelein et al. (2015) study, about which we have expressed reservations above. Due to the scarcity of relevant data to address such a wide range of marine mammal species exposed to a variety of sound sources, the usual standards for statistical robustness, particularly avoiding pseudo replication, were not always met, potentially introducing bias (Wright, 2015; Tougaard et al., 2015). There are also insufficient data to model recovery after TTS and, therefore, determine the intervening time necessary to treat multiple exposures as separate events (Finneran, 2015). This deficiency is clearly relevant for sounds which occur in bouts, such as pile-driving. Lastly, Hector's dolphin hearing has never been tested. While it is likely to be similar to that of harbour porpoise, the uncertainty associated with this assumption is potentially significant, particularly when the choice of weighting function is critical in noise regulation (Tougaard and Dähne, 2017).

Given the endangered status of Hector's dolphin it is imperative that additional threats, including those from noise pollution, are minimised. Bubble curtains can significantly reduce the noise radiated into the water column (Lucke et al., 2011; Nehls et al., 2016; Tsouvalas and Metrikine, 2016b) particularly when confined (e.g Buehler et al., 2015). For Lyttelton Harbour, however, significant re-suspension of sediment could breach a condition of the Coastal Permit, and therefore make bubble curtains an unlikely noise-mitigation option for future construction work. Another strategy for reducing noise pollution could be to employ screw-piling technology, rather than impact pile-driving, which produces significantly less underwater noise (Saleem, 2011).

Declarations of interest

None.

Acknowledgements

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References

Ainslie, M.A., McColm, J.G., 1998. A simplified formula for viscous and chemical absorption in sea water. J. Acoust. Soc. Am. 103, 1671–1672. https://doi.org/10.1121/1.421258.

Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G., Thompson, P.M., 2010. Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals. Mar. Pollut. Bull. 60, 888–897. https://doi.org/10.1016/j.marpolbul.2010.01.003.

Blackwell, S.B., 2005. Underwater measurements of pile-driving sounds during the Port MacKenzie dock modifications, 13-16 August 2004. Rep. from Greeneridge Sciences, Inc., Goleta, CA, and LGL Alaska Research Associates, Inc., Anchorage, AK, in association with HDR Alaska, Inc., Anchorage, AK, for Knik Arm Bridge and Toll Authority, Anchorage, AK, Department of Transportation and Public Facilities, Anchorage, AK, and Federal Highway Administration, Juneau, AK. pp. 33.

Brandt, M.J., Diederichs, A., Betke, K., Nehls, G., 2011. Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Mar. Ecol. Prog. Ser. 421, 205–216. https://doi.org/10.3354/meps08888.

Buehler, D., Oestman, R., Reyff, J., Pommerenck, K., Mitchell, B., 2015. Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish. Report No. CTHWANP-RT-15-306.01.01. Division of Environmental Analysis, California Department of Transportation.

Canterbury Earthquake Recovery Act, New Zealand Legislation, 2011. http://www.legislation.govt.nz/act/public/2011/0012/latest/DLM3653522.html (New Zealand).

Cobo, P., Kormann, J., Ranz Guerra, C., 2007. Underwater noise impact of offshore wind farms during construction and operation phases. In: 14th International Congress on Sound and Vibration, pp. 8 (Cairns).

Dähne, M., Gilles, A., Lucke, K., Peschko, V., Adler, S., Krügel, K., Sundermeyer, J., Siebert, U., 2013. Effects of pile-driving on harbour porpoises (*Phocoena phocoena*) at the first offshore wind farm in Germany. Environ. Res. Lett. 8 (16). https://doi.org/10.1088/1748-9326/8/2/025002.

Dawson, S.M., 2018. Cephalorhynchus dolphins. In: Perrin, W.F., Würsig, B., Thewissen,

J.G.M. (Eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, pp. 166–172.
Dawson, S.M., Thorpe, C.W., 1990. A quantitative-analysis of the sounds of hector dolphin. Ethology 86, 131–145.
De Jong, C.A.F., Ainslie, M.A., 2008. Underwater radiated noise due to the piling for the Q7 Offshore Wind Park. J. Acoust. Soc. Am. 123, 2987. https://doi.org/10.1121/1.2932518.
De Jong, C.A.F., Ainslie, M.A., Blacquière, G., 2011. Standard for Measurement and Monitoring of Underwater Noise, Part II: Procedures for Measuring Underwater Noise in Connection With Offshore Wind Farm Licensing. Rep. No. TNO-DV. pp. 42.
Denes, S.L., Warner, G.A., Austin, M.E., MacGillivray, A.O., 2016. Hydroacoustic Pile Driving Noise Study-comprehensive Report. Document 001285. Version 2.0. Technical report by JASCO Applied Sciences for Alaska Department of Transportation & Public Facilities.
Duncan, A.J., Mccauley, R.D., Parnum, I., Salgado-Kent, C., 2010. Measurement and Modelling of Underwater Noise from Pile Driving. In: 20th International Congress on Acoustics, pp. 1–5.
Dyndo, M., Wiśniewska, D.M., Rojano-Doñate, L., Madsen, P.T., 2015. Harbour porpoises react to low levels of high frequency vessel noise. Sci. Rep. 5, 1–9. https://doi.org/10.1038/srep11083.
Finneran, J.J., 2015. Noise-induced hearing loss in marine mammals: a review of temporary threshold shift studies from 1996 to 2015. J. Acoust. Soc. Am. 138, 1702–1726. https://doi.org/10.1121/1.4927418.
Forney, K.A., Southall, B.L., Slooten, E., Dawson, S., Read, A.J., Baird, R.W., Brownell, R.L., 2017. Nowhere to go: noise impact assessments for marine mammal populations with high site fidelity. Endanger. Species Res. 32, 391–413. https://doi.org/10.3354/esr00820.
Forrest, T.G., Miller, G.L., Zagar, J.R., 1993. Sound propagation in shallow water: implications for acoustic communication by aquatic animals. Bioacoustics 4, 259–270. https://doi.org/10.1080/09524622.1993.10510437.
Fricke, M.B., Rolfes, R., 2015. Towards a complete physically based forecast model for underwater noise related to impact pile driving. J. Acoust. Soc. Am. 137, 1564–1575. https://doi.org/10.1121/1.4908241.
Hermannsen, L., Beedholm, K., Tougaard, J., Madsen, P.T., 2014. High frequency components of ship noise in shallow water with a discussion of implications for harbor porpoises (*Phocoena phocoena*). J. Acoust. Soc. Am. 136, 1640–1653. https://doi.org/10.1121/1.4893908.
Jensen, F.B., Kuperman, W.A., Porter, M.B., Schmidt, H., 2011. Computational Ocean Acoustics. Springer Science & Business Media, pp. 29–30.
Kastelein, R.A., Bunskoek, P., Hagedoorn, M., Au, W.W.L., de Haan, D., 2002. Audiogram of a harbor porpoise (*Phocoena phocoena*) measured with narrow-band frequency-modulated signals. J. Acoust. Soc. Am. 112, 334–344. https://doi.org/10.1121/1.1480835.
Kastelein, R.A., van Heerden, D., Gransier, R., Hoek, L., 2013a. Behavioral responses of a harbor porpoise (*Phocoena phocoena*) to playbacks of broadband pile driving sounds. Mar. Environ. Res. 92, 206–214. https://doi.org/10.1016/j.marenvres.2013.09.020.
Kastelein, R.A., Hoek, L., Gransier, R., de Jong, C.A.F., 2013b. Hearing thresholds of a harbor porpoise (*Phocoena phocoena*) for playbacks of multiple pile driving strike sounds. J. Acoust. Soc. Am. 134, 2302–2306. https://doi.org/10.1121/1.4817842.
Kastelein, R.A., Gransier, R., Marijt, M.A.T., Hoek, L., 2015. Hearing frequency thresholds of harbor porpoises (*Phocoena phocoena*) temporarily affected by played back offshore pile driving sounds. J. Acoust. Soc. Am. 137, 556–564. https://doi.org/10.1121/1.4906261.
Lepper, P.A., Robinson, S.P., Ablitt, J., 2009. Temporal and spectral characteristics of a marine piling operation in shallow water. In: NAG/DAGA International Conference on Acoustics 2009, pp. 266–268.
Leunissen, E., 2017. Underwater Noise From Pile-driving and Its Impact on Hector's Dolphins in Lyttelton Harbour, New Zealand. University of Otago.
Lippert, T., von Estorff, O., 2014. The significance of parameter uncertainties for the prediction of offshore pile driving noise. J. Acoust. Soc. Am. 136, 2463–2471. https://doi.org/10.1121/1.4896458.
Lucke, K., Siebert, U., Lepper, P.A., Blanchet, M.-A., 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. J. Acoust. Soc. Am. 125, 4060–4070. https://doi.org/10.1121/1.3117443.
Lucke, K., Lepper, P.A., Blanchet, M.-A., Siebert, U., 2011. The use of an air bubble curtain to reduce the received sound levels for harbor porpoises (*Phocoena phocoena*). J. Acoust. Soc. Am. 130, 3406–3412. https://doi.org/10.1121/1.3626123.
Madsen, P.T., 2005. Marine mammals and noise: problems with root mean square sound pressure levels for transients. J. Acoust. Soc. Am. 117, 3952–3957. https://doi.org/10.1121/1.1921508.
Malme, C.I., Beranek, B., 1995. Sound propagation. In: Richardson, W., Greene Jr.C., Malme, C., Thomson, D. (Eds.), Marine Mammals and Noise, pp. 59–86.
Marsh, H.W., Schulkin, M., 1962. Shallow-water transmission. J. Acoust. Soc. Am. 34, 863–864.
Merchant, N.D., Fristrup, K.M., Johnson, M.P., Tyack, P.L., Witt, M.J., Blondel, P., Parks, S.E., 2015. Measuring acoustic habitats. Methods Ecol. Evol. 6, 257–265. https://doi.org/10.1111/2041-210X.12330.
Mooney, T.A., Nachtigall, P.E., Breese, M., Vlachos, S., Au, W.W.L., 2009. Predicting temporary threshold shifts in a bottlenose dolphin (*Tursiops truncatus*): the effects of noise level and duration. J. Acoust. Soc. Am. 125, 1816–1826. https://doi.org/10.1121/1.3068456.
National Marine Fisheries Service, 2016. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. NOAA Technical Memorandum NMFS-OPR-55 U.S. Dept. of Commer., NOAA (https://doi.org/NMFS-OPR-55).
Nedwell, J.R., Parvin, S.J., Edwards, B., Workman, R., Brooker, A.G., Kynoch, J.E., 2007. Measurement and Interpretation of Underwater Noise during Construction and Operation of Offshore Windfarms in UK Waters, Cowrie Noise-03-2003.
Nehls, G., Rose, A., Diederichs, A., Bellmann, M., Pehlke, H., 2016. Noise mitigation during pile driving efficiently reduces disturbance of marine mammals. In: The Effects of Noise on Aquatic Life II. Springer, pp. 755–762.
Norton, G.V., Novarini, J.C., 1996. The effect of sea-surface roughness on shallow water waveguide propagation: a coherent approach. J. Acoust. Soc. Am. 99, 2013. https://doi.org/10.1121/1.415388.
OCEL Consultants NZ Limited, 2014. EFFECTS ON SEDIMENTATION AND TURBIDITY. Lyttelton Port Company, Christchurch, pp. 70. http://www.lpc.co.nz/wp-content/uploads/2015/09/Appendix-14-Effects-on-Sedimentation-and-Turbidity.pdf.
Paiva, E.G., Salgado Kent, C.P., Gagnon, M.M., McCauley, R., Finn, H., 2015. Reduced detection of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in an Inner Harbour channel during pile driving activities. Aquat. Mamm. 41, 455–468. https://doi.org/10.1578/AM.41.4.2015.455.
Parra, G.J., Jefferson, T.A., 2018. Humpback dolphins. In: Perrin, W.F., Würsig, B., Thewissen, J.G.M. (Eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, pp. 483–488.
Pine, M.K., Jeffs, A.G., Radford, C.A., 2014. The cumulative effect on sound levels from multiple underwater anthropogenic sound sources in shallow coastal waters. J. Appl. Ecol. 51, 23–30. https://doi.org/10.1111/1365-2664.12196.
R Development Core Team, 2006. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria3-900051-07-0. http://www.R-project.org.
Rayment, W., Dawson, S., Slooten, L., 2009. Trialling an automated passive acoustic detector (T-POD) with hector's dolphins (*Cephalorhynchus hectori*). J. Mar. Biol. Assoc. UK 89, 1015–1022. https://doi.org/10.1017/S0025315409003129.
Reinhall, P.G., Dahl, P.H., 2011. Underwater Mach wave radiation from impact pile driving: theory and observation. J. Acoust. Soc. Am. 130, 1209–1216. https://doi.org/10.1121/1.3614540.
Richardson, W.J., Greene Jr., C.R., Malme, C.I., Thomson, D.H., 2013. Marine Mammals and Noise. Academic Press.
Robinson, S.P., Lepper, P.A., Ablitt, J., 2007. The measurement of the underwater radiated noise from marine piling including characterisation of a “soft start” period. In: Ocean. 2007-Europe, pp. 1–6.
Rossington, K., Benson, T., Lepper, P., Jones, D., 2013. Eco-hydro-acoustic modeling and its use as an EIA tool. Mar. Pollut. Bull. 75, 235–243. https://doi.org/10.1016/j.marpolbul.2013.07.024.
Saleem, Z., 2011. Alternatives and Modifications of Monopile Foundation or Its Installation Technique for Noise Mitigation. Report by Delft University of Technology for Stichting De Noordzee (the North Sea Foundation). pp. 68. (Delft). www.vliz.be/imisdocs/publications/223688.pdf.
Shumway, G., 1960. Sound speed and absorption studies of marine sediments by a resonance method. Geophysics 25, 451–467.
Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene Jr., C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W., Thomas, J., Tyack, P.L., 2007. Aquatic mammals-marine mammal noise exposure criteria: initial scientific recommendations. Aquat. Mamm. 33, 411–521. https://doi.org/10.1578/AM.33.4.2007.411.
Thompson, P.M., Hastie, G.D., Nedwell, J., Barham, R., Brookes, K.L., Cordes, L.S., Bailey, H., McLean, N., 2013. Framework for assessing impacts of pile-driving noise from offshore wind farm construction on a harbour seal population. Environ. Impact Assess. Rev. 43, 73–85. https://doi.org/10.1016/j.eiar.2013.06.005.
Tougaard, J., Dähne, M., 2017. Why is auditory frequency weighting so important in regulation of underwater noise? J. Acoust. Soc. Am. 142, EL415–EL420. https://doi.org/10.1121/1.5008901.
Tougaard, J., Carstensen, J., Teilmann, J., Skov, H., Rasmussen, P., 2009. Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (*Phocoena phocoena* (L.)). J. Acoust. Soc. Am. 126, 11–14. https://doi.org/10.1121/1.3132523.
Tougaard, J., Wright, A.J., Madsen, P.T., 2015. Cetacean noise criteria revisited in the light of proposed exposure limits for harbour porpoises. Mar. Pollut. Bull. 90, 196–208. https://doi.org/10.1016/j.marpolbul.2014.10.051.
Tsouvalas, A., Metrikine, A.V., 2013. A semi-analytical model for the prediction of underwater noise from offshore pile driving. J. Sound Vib. 332, 3232–3257. https://doi.org/10.1016/j.jsv.2013.01.026.
Tsouvalas, A., Metrikine, A., 2016a. Structure-borne wave radiation by impact and vibratory piling in offshore installations: from sound prediction to auditory damage. J. Mar. Sci. Eng. 4, 44. https://doi.org/10.3390/jmse4030044.
Tsouvalas, A., Metrikine, A.V., 2016b. Noise reduction by the application of an air-bubble curtain in offshore pile driving. J. Sound Vib. 371, 150–170. https://doi.org/10.1016/j.jsv.2016.02.025.
Urick, R.J., 1983. Principles of Underwater Sound, 3rd ed. Peninsula Publishing, California, pp. 17–202.
Villadsgaard, A., Wahlberg, M., Tougaard, J., 2007. Echolocation signals of wild harbour porpoises, *Phocoena phocoena*. J. Exp. Biol. 210, 56–64. https://doi.org/10.1242/jeb.02618.
Wright, A.J., 2015. Sound science: maintaining numerical and statistical standards in the pursuit of noise exposure criteria for marine mammals. Front. Mar. Sci. 2, 1–6. https://doi.org/10.3389/fmars.2015.00099.
Würsig, B., Greene, C.R., Jefferson, T.A., 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling. Mar. Environ. Res. 49, 79–93. https://doi.org/10.1016/S0141-1136(99)00050-1.
Würsig, B., Thewissen, J.G.M., Kovacs, K.M., 2018. Encyclopedia of Marine Mammals. Academic Press, pp. 166–450.
Yoder, N., 2009. Peakfinder. Mathworks File Exchange. https://www.mathworks.com/matlabcentral/fileexchange/25500-peakfinder-x0–sel–thresh–extrema–includeendpoints–interpolate-.

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Impact of pile-driving on Hector's dolphin in Lyttelton Harbour, New Zealand

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ABSTRACT

Several dolphin species occur close inshore and in harbours, where underwater noise generated by pile-driving used in wharf construction may constitute an important impact. Such impacts are likely to be greatest on species such as the endangered Hector's dolphin (*Cephalorhynchus hectori*), which has small home ranges and uses this habitat type routinely. Using automated echolocation detectors in Lyttelton Harbour (New Zealand), we studied the distribution of Hector's dolphins using a gradient sampling design over 92 days within which pile-driving occurred on 46 days. During piling operations, dolphin positive minutes per day decreased at the detector closest to the piling but increased at the mid-harbour detector. Finer-grained analyses showed that close to the piling operation, detections decreased with increasing sound exposure level, that longer piling events were associated with longer reductions in detections, and that effects were long-lasting - detection rates took up to 83 h to return to pre-piling levels.

1. Introduction

The increase in anthropogenic noise in the ocean (e.g. McDonald et al., 2008) has resulted in growing interest in researching the impact of noise on marine mammals, in particular cetaceans. Since cetaceans rely on sound for foraging and sociality, it is important to know how the additional noise may affect them. Negative impacts on marine mammals have been observed from sources including airgun pulses used in seismic surveys (e.g. Romano et al., 2004; Lucke et al., 2009; Gray and van Waerebeek, 2011), shipping (Aguilar Soto et al., 2006; Castellote et al., 2012; Rolland et al., 2012) and sonars (e.g. Fernández et al., 2005; Filadelfo et al., 2009; Tyack et al., 2011). Pile-driving, another source of underwater noise pollution, is of special concern since the noise is loud, impulsive and broadband in frequency (Madsen et al., 2006). Effects on endemic, endangered species, especially those with small home ranges, are of particular interest in this context.

Harbour porpoise (*Phocoena phocoena*) has very similar acoustic behaviour (Dawson, 2018; Dawson and Thorpe, 1990; Villadsgaard et al., 2007) to Hector's dolphin, and is similar in size and ecology (Würsig et al., 2018). Harbour porpoises show strong avoidance reactions to pile-driving noise (Carstensen et al., 2006; Thompson et al., 2010; Tougaard et al., 2009; Brandt et al., 2011; Brandt et al., 2016). These studies used passive acoustic monitoring devices (T-PODs or C-PODs) at increasing distances from the piling to investigate changes in detection rates of echolocation clicks. Tougaard et al. (2009) and Brandt et al. (2011) found a marked decrease in porpoise clicks over a radius of at least 20 km from the piling. At close range (2.6 km from the source), this response lasted up to 72 h after piling ceased (Brandt et al., 2011). Aerial surveys confirmed that porpoises actually left the area rather than becoming silent (Dähne et al., 2013). Piling noise also affected echolocation rate, however, as a sudden decrease in click rate was observed following the onset of piling (Brandt et al., 2011).

Broadly similar responses have also been observed in Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in Fremantle Harbour, Australia. Video recordings made in a harbour channel showed significantly fewer visual detections during pile-driving activity for wharf construction (Paiva et al., 2015). This study could not, however, determine whether decreased detections were due to decreased use of that habitat. Alternative explanations include that masking of communication signals may have led to reduced surface socialising, that detection of prey by echolocation may have been impeded, and/or that the effect of pile-driving may have been indirect (e.g. on prey abundance or their availability).

Hector's dolphin (*Cephalorhynchus hectori*), is an endangered delphinid found only in New Zealand. This species uses high frequency click trains for echolocation and communication. These clicks are about 140 ms in duration and most are centred at a frequency of 125 kHz (Dawson and Thorpe, 1990). Hector's dolphin signals are low-level

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compared to those recorded from other cetaceans, with an estimated peak-to-peak source level of 161–187 dB re 1 μPa @ 1 m (Kyhn et al., 2009). For harbour porpoise this is 178–205 dB re 1 μPa @ 1 m (Villadsgaard et al., 2007). There are no data on the hearing sensitivity of Hector's dolphin.

Hector's dolphin have one of the smallest documented home ranges of any dolphin species (Rayment et al., 2009a) and favours inshore waters, frequently entering harbours (Dawson et al., 2013). The principal threat to the species, incidental catch in gillnets and trawls, resulted in the establishment of the Banks Peninsula Marine Mammal Sanctuary in 1988, and 20 years later, extensive further closures to gillnetting (Slooten and Dawson, 2010).

Construction work for the development of Port Lyttelton, in anticipation of a growing increase in container cargo, was combined with earthquake repair work. This work included 15 months of pile-driving, and more is scheduled for 2019. Hector's dolphins are routinely present in Lyttelton Harbour (Brough et al., 2014, in press; Leunissen and Dawson, 2018). Pile-driving could be an additional impact on Hector's dolphin and provides the context for this study. Underwater recordings made in Lyttelton Harbour at close range to the piling (up to 370 m) show broadband, impulsive strikes with high peak-to-peak SPLs. Maximum calculated source sound exposure level (SEL) was 192 dB re 1μPa^{2}s @ 1 m (zero-to-peak sound pressure level ($SPL_{0\text{-}p}$) of 213 dB re 1 μPa @ 1 m: Leunissen and Dawson, 2018). All three drivers produced a similar distribution of energy across the frequency range, the highest energy was around 200–300 Hz. While most energy was between 50 Hz-10 kHz, there was some energy to at least 100 kHz (Leunissen and Dawson, 2018).

Since Hector's dolphins have small home ranges, and the pile-driving in Lyttelton occurred within a confined harbour environment, there is a high chance that this operation had a significant impact on the local Hector's dolphins. In a previous paper we provided measurements of the pile-driving sounds and their propagation within this harbour environment (Leunissen and Dawson, 2018). In this study we attempt to measure impact on the dolphins' distribution within Lyttelton Harbour. In particular, does the detection rate change after a pile-driving event? If there is an effect, how long does this last following the pile-driving event?

2. Methods

2.1. Field techniques

Pile-driving was used extensively in the reconstruction of one of the main wharves (Cashin Quay 2) in Lyttelton Harbour, New Zealand (43.6033° S, 172.7227° E) (Fig. 1). Piles were driven within an area 77 m long (along the wharf) and 24 m wide (see 'Pile-driving' in Fig. 1). This area contained 90 pile locations, of which 57 were driven during our study (between December 19th, 2014 and March 25th, 2015). Three different pile drivers were used with hammer weights of nine, ten and 14 t, with a maximum blow energy of 206 kJ. The hollow steel piles had diameters of 0.61 or 0.71 m, and were driven an average of 66 m into the seabed (HEB construction, pers. comm. 2015). A "soft start" using the hammer on its lowest energy setting for the first 2 min, was standard practice (i.e. required by the pile-driver manufacturers).

Echolocation detectors (v.5 T-PODs, numbers 755, 775 & 776, Chelonia Ltd) were moored in Lyttelton Harbour from December 19th, 2014 to March 25th, 2015, 2 m from the seabed, at distances of 1300, 2000, and 6150 m respectively from the piling. This deployment follows a gradient sampling design (Thompson et al., 2010; Brandt et al., 2011) and enables detection of temporal effects with distance. The sites were chosen to represent inner, mid and outer harbour sites (Fig. 1) while considering the safety of our equipment for long term deployment in a busy harbour. The inner T-POD at 1300 m was, therefore, at the closest practical distance to the pile-driving. The inner and mid T-PODs were moored near existing harbour markers. The outer T-POD was moored in a bay well clear of shipping traffic, with a buoy at the surface (see Table 1 for properties of the sites where T-PODs were moored).

T-PODs were serviced (data downloaded, batteries replaced, fouling removed) on 7 January 2015 (re-deployed on the same day) and 27 February 2015 (re-deployed on 5 March 2015 due to unsuitable weather conditions). The same T-PODs were used at their respective sites for the entire monitoring period, except for the outer site. The outer T-POD became detached from its mooring between 7 January and 27 February, and was not recovered. This T-POD was replaced with a new device (v.4 No. 484, Chelonia Ltd). The aim of acoustic monitoring was to detect changes in acoustic activity in relation to pile-driving noise. Sensitivities of the T-POD versions used in the current study (v. 4 and 5) are similar and much more standardised than previous versions (Dähne et al., 2006; Verfuß et al., 2008). Hence, any differences in detection rates are likely negligible (see also Dawson et al., 2013).

In all T-POD deployments, five scans were optimised for detection of Hector's dolphins (target filter frequency = 130 kHz; reference frequency = 92 kHz; bandwidth = 4; noise adaptation = + +; sensitivity = 10; scan limit = 240). One scan was set at a lower frequency to discriminate between Hector's dolphins and other delphinids (target filter frequency = 50 kHz; reference frequency = 70 kHz; sensitivity = 6). The same settings were used as in Dawson et al. (2013) studying Hector's dolphin habitat use and Rayment et al. (2011) detecting Maui's dolphin (*Cephalorynchus hectori maui*) clicks. Other studies using T-PODs employed a similar strategy to discriminate between detections of harbour porpoises and bottlenose dolphins (e.g. Philpott et al., 2007; Bailey et al., 2010). The detection radius of T-PODs detecting Hector's dolphins is 198–239 m (Rayment et al., 2009b).

Pile-driving noise levels were recorded continuously throughout the study via a DSG recorder (Loggerhead Instruments; HTI-96 min hydrophone, max. Frequency response 2–30 kHz) moored in Diamond Harbour (see Fig. 1). This recorder was set to sample at 2500 Hz to allow an extended recording period. While this sample rate could not capture the full spectrum of piling noise (i.e., only up to 1250 Hz), the recordings allowed incorporation of relative intensity of pile-driving noise into the statistical analysis of echolocation detections.

Noise levels were measured and modelled throughout the harbour (see Leunissen and Dawson, 2018 for more detail). The sound levels at each T-POD location are summarised in Table 1.

2.2. Analyses

TPOD data were processed using the manufacturer's software (T-POD.exe v8.24). This software classifies clicks according to the likelihood they were of cetacean origin. The categories CET HI and CET LO (combined as 'Cet All') reliably represent Hector's dolphin detections (Rayment et al., 2009b), and are used here. Using only 'Cet All' detections, however, results in a conservative account of habitat use as many genuine trains are classified as DOUBTFUL (Rayment et al., 2009b; see also Thomsen et al., 2005, for a similar result from harbour porpoise).

Click data were exported as detection positive minutes (DPM) per hour - the number of minutes per hour in which dolphin clicks were detected, and DPM per day – the number of minutes per day in which dolphin clicks were detected. DPM (measured over a given time period) is the recommended metric for studying habitat use and behaviour (Chelonia Ltd. 2007), has been used in other studies assessing impacts of pile-driving (Brandt et al., 2011, 2016; Degraer et al., 2012), and has the advantage of reducing the effect of variation in sensitivity among T-PODs (Dähne et al., 2006). The DPM per hour measure allowed tracking of the post pile-driving echolocation activity on a fine temporal scale.

Mean SEL was used to account for pile-driving strike intensity. It was generally not possible to calculate the SEL for every strike within an hour, due to variation in ambient noise (such as water flow noise or passing boats). Therefore, a representative sample of ten pile strikes was used to calculate the mean pile strike SEL for each hour. The

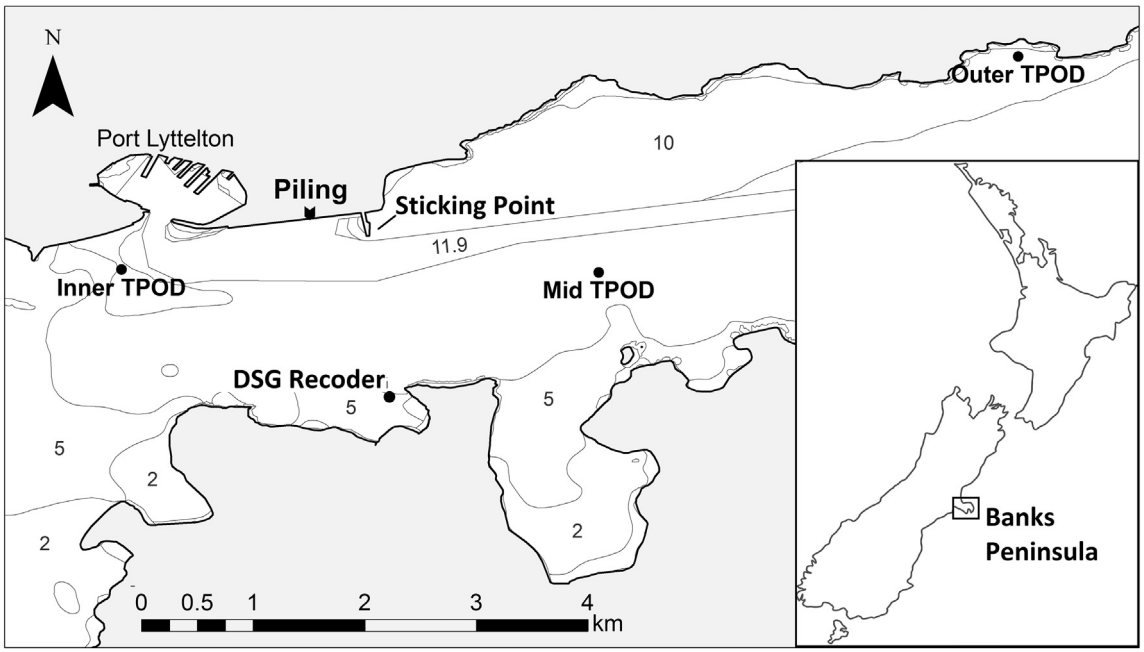

Fig. 1. Locations of T-POD monitors, DSG recorder and pile-driving in Lyttelton Harbour. Numbers within gray contour lines indicate depth (m). Inset: Map of New Zealand.

Table 1
Site properties for each T-POD location. Substrate information obtained from Chart NZ 6321 (www.linz.govt.nz).

Site	Range to piling (m)	Range to nearest shore (m)	Substrate	Water depth (m)	SEL (mean, max; dB re 1μPa^{2}s)	SPL_{0p} (mean; dB re 1μPa)
Inner	1300	330	Mud/Shell	4	127, 137	158
Mid	2000	890	Sand/Mud/Shell	8	114, 124	145
Outer	6150	125	Mud	7	90, 100	121

sample was chosen (through visual inspection of the hour's waveform in Audacity) to avoid strikes masked by ambient noise, and such that the peak pressure in the strikes' waveforms were at midrange of the peak pressures of all strikes within the hour. Peak pressure was proportional to SEL (Leunissen and Dawson, 2018). SEL per day was calculated as the mean across all hours which contained pile-driving. To quantify how long any effect lasted following a pile-driving event (where a new event was defined when the time between consecutive strikes, from one pile driver, exceeded 1 min), the variable "time-since-piling" was included. The duration of previous pile-driving events was also included. For each hour this was calculated as the total piling-positive-minutes (PPM) within previous consecutive hours containing pile-driving, up to the current hour. The duration of piling per day was calculated as total PPM across all hours for that day. Hourly wind data were provided by Metservice (www.metservice.com). This variable was relevant because in shallow water sound does not propagate as far at high wind speeds due to decreased reflection at the roughly textured water surface (Norton and Novarini, 1996). Increasing aeration of the water also reduces propagation (Mallock, 1910). This could lead to lower click detection rates at higher wind speeds (e.g. Brandt et al., 2016). Time of day and time since high tide were included in our models as they have been shown to influence Hector's dolphin distribution in Akaroa Harbour, on the south side of Banks Peninsula (Dawson et al., 2013).

2.3. Statistical analyses

Statistical analyses were carried out using the software package R (v 3.2.4, The R Foundation for Statistical Computing, 2016). The effect of pile-driving noise on dolphin detections was investigated using an information theoretic approach (Anderson et al., 2000; Burnham and Anderson, 2002), by comparing a suite of competing explanatory models. The two response variables were DPM per hour and DPM per day. Response variables were not normally distributed. Visual comparison of fitted Gaussian, Poisson and negative binomial distributions, and Q-Q plots indicated that the negative binomial distribution provided the closest fit to both response variables.

Explanatory variables consisted of piling-related, time-related and environmental variables (Tables 2 and 3). Collinearity among explanatory variables was assessed using variance inflation factors (VIFs). A cut-off value of three (Zuur et al., 2011), was not exceeded, indicating that collinearity was not significant.

A 17 day hiatus in pile-driving over the Christmas-New Year period was much longer than any other break in piling activity (max. 90 h). The DPM per hour dataset was restricted to include data for which time-since-piling did not exceed 150 h. This limit is more than twice as long as the longest duration of impact observed in harbour porpoise studies (72 h; Brandt et al., 2011).

The effect of explanatory variables on response variables was investigated using Generalised Additive Models (GAMs; Hastie and Tibshirani, 1990) with a negative binomial response (using the package *mgcv* in R). GAMs fit a sum of smooth functions for each covariate, and are particularly useful for modelling the non-linear relationships between cetacean distribution and environmental variables (Ferguson et al., 2005; Torres et al., 2008; Embling 2009). Since the model is additive, the effect of each covariate is considered in addition to the effects of the other covariates (Hastie and Tibshirani, 1990). The choice of basis dimension for smoothing terms was not restricted and left to be chosen during the modelling process for best fit.

Explanatory variables were expected to have a different effect on the response variable based on T-POD location. Therefore, a factor

Table 2
List of explanatory variables used in the models of DPM per day.

Variable (abbreviation)	Type	Description
Piling related variables		
Sound Exposure Level (SEL)	Continuous	Mean sound exposure level (dB re 1 μPa^{2}s) for each day as measured at the Diamond Harbour DSG
Piling positive minutes (PPM)	Continuous	Total number of minutes that contained pile-driving noise each day
Time related variables		
Previous DPM (DPMt-1)	Continuous	DPM measured during previous day.
Environmental variables		
Wind speed (Wspd)	Continuous	Measured in knots at 9 am each day
Wind direction (Wdir)	Continuous, cyclic	Measured in degrees at 9 am each day
T-POD position (TPOD)	Factor, 3 levels	Inner (1), mid (2) or outer (3) harbour position

interaction term (using the tensor product interaction function *ti* with the 'by = TPOD' argument), which fitted a separate smoothing function for each of the three T-POD locations, was also tested (as well as testing a smoothing function *s* for each variable across all T-POD locations combined). Models never contained both the smoothing function of the variable and the factor interaction term as this would include the same variable twice. All smoothed functions were fitted using the default spline (cubic regression spline for *ti* and thin-plate regression spline for *s*), except for the circular variables (tide, time of day and wind direction). These variables were fitted with a cyclic cubic regression spline.

Response variables were temporally auto-correlated (tested using the auto-correlation function *acf* in the R package *stats*). One method to account for correlation is to use a correlation structure in a Generalised Additive Mixed Model (GAMM). For our data, this approach (using a corAR1 structure) produced marginal reductions in temporal auto-correlation, and produced models for which normality was not satisfied (verified via Q-Q plots). Instead, we introduced an explanatory variable with the value of the response at a previous point in time (in this case DPM of the previous hour or day; Tables 2 and 3), an approach used by Brandt et al. (2016) in their T-POD study of pile-driving effects on harbour porpoise. This considerably reduced the effect of temporal autocorrelation in the resulting models (see Appendix A).

A suite of GAMs was constructed and their performances compared via AICc. Model selection was conducted using forward step-wise selection (see Zuur et al., 2009). The Akaike weight was also calculated for each model, and can be interpreted as the approximate likelihood that the model is the best in the set (Anderson et al., 2000). The index of relative importance (IRI) was used to rank the importance of each variable (Burnham and Anderson, 2002). While model averaging can be useful for linear regression models, averaging structural parameters in some non-linear models is not recommended (Burnham and Anderson, 2002). Also, the coefficients for the categorical variable (T-POD) were very similar across all top models. Hence, we have not presented any model averaged results.

An interaction between time-since-piling (TSP) and duration-of-piling (Dur) was included in the modelling of DPM per hour. This was done to investigate if piling events of longer duration increased the length of time that detection rates were affected after piling. A contour plot was used to illustrate the effect of this interaction. This required all other explanatory variables to be fixed. SEL and DPMt-1 were fixed at their respective mean values, and Hour, Tide and Wdir were fixed at values at which DPM per hour at the inner harbour was predicted to be high by the models (i.e. when dolphins were likely to be present in the inner harbour).

Relationships were considered statistically significant at alpha = 0.05. Model validity was verified using diagnostic plots (Q-Q plots and histograms to check normality, residuals vs linear predictor to check heterogeneity, and response vs fitted values to check model fit, using randomised quantile residuals to account for the negative binomial distribution).

3. Results

This study consisted of 92 days of T-POD monitoring at the inner and mid sites, and 41 days at the outer site (Table 4), yielding a combined total of 5256 T-POD hours. During this period pile-driving occurred on 46 days, with a mean of 125.5 mins of piling per day (SE = 16.7 mins). This average excluded the 17-day break over

Table 3
List of explanatory variables used in the models of DPM per hour.

Variable (abbreviation)	Type	Description
Piling related variables		
Sound Exposure Level (SEL)	Continuous	Mean sound exposure level (dB re 1 μPa^{2}s) of a representative sample of 10 strikes per hour as measured at the Diamond Harbour DSG
Time since piling (TSP)	Continuous	Equals '0' during hours of piling, otherwise equals the minutes since the previous piling event.
Piling duration (Dur)	Continuous	Duration of the previous piling event in minutes.
Time related variables		
Hour of day (Hour)	Continuous, cyclic	Equals '0' for the hour starting at 00:00 am, to '23' for the hour starting at 11:00 pm
Previous DPM (DPMt-1)	Continuous	DPM measured in the preceding hour.
Environmental variables		
Wind speed (Wspd)	Continuous	Averaged over the 10 min directly preceding each hour, measured in knots
Wind direction (Wdir)	Continuous, cyclic	Averaged over the 10 min directly preceding each hour, measured in degrees
T-POD position (TPOD)	Factor, 3 levels	Inner (1), mid (2) or outer (3) harbour position
Tide (tide)	Continuous, cyclic	Hours since last high tide

Table 4
T-POD deployment and detections. 'Detection positive days' is the number of days on which at least one dolphin click was detected. DPM = detection positive minutes; SE = standard error.

T-POD	Days deployed	Detection positive days	Mean DPM per day (SE)
Inner	92	82	12.83 (1.52)
Mid	92	91	29.47 (1.97)
Outer	41	41	55.27 (6.40)

Christmas-New Year during which no pile-driving occurred. The outer T-POD, while in place, had consistently more detections of Hector's dolphins than the other two (Table 4).

3.1. DPM per day

The model which included the piling-related variable PPM was the top model, and had a higher Akaike weight than those that did not (Table 5). The effect of many of the variables differed by location (Table 6).

An increase in PPM per day led to a decrease in DPM per day at the inner and outer T-PODs, and an increase in DPM at the mid T-POD (Fig. 2). The variable SEL was not present in the top models.

DPM per day decreased with increasing wind speed at the inner and mid T-POD (Fig. 2). At the inner T-POD, increased detections were seen during westerly winds, and decreased detections during easterly winds (Fig. 2).

3.2. DPM per hour

The six highest rated models, by Akaike weight, all contained three piling-related variables (TSP, SEL and Dur), the 7th and lowest rated model contained two piling-related variables. Relationships among variables were more complex in the DPM per hour dataset, for which top models included all variables tested, as well as the interaction between time-since-piling and duration-of-piling (Tables 7 and 8).

The lowest detection rate at the inner T-POD was seen within 2000 mins (33 h) after piling (Fig. 3). After this point the rate steadily increased and levelled off around 5000 mins (83 h). DPM per hour decreased with increasing SEL at all T-POD locations (Fig. 3). An increase in duration of pile-driving led to a decrease in detection rate, up to a duration of about 150 mins (Fig. 4). The interaction between time-since-piling (TSP) and duration-of-piling (Dur), at the inner T-POD, showed decreasing detection rates within the first 2000 mins (33 h) of piling (Fig. 5). Detection rates returned to the level of the previous hour (set at 1.1 DPMs) after 3000–3500 min (50–58 h) (Fig. 5). The first maximum following the minimum occurred at 5000 min. Therefore, this time most likely represents the time to recovery, see Brandt et al. (2011). There were more subtle effects with duration. For short duration events (< 100 min) the lowest DPM per hour was seen directly after piling, and was lower than that of the previous hour (Fig. 5). For longer duration events, however, the lowest DPM was seen around 2000 mins (33 h) after piling, as shown by the 0.4 contour (Fig. 5). Beyond 5000 mins after piling, DPM per hour decreased with time.

At the inner T-POD, detection rates were highest around 5–6 am and the lowest around 11–12 pm, with another peak in detections at 5–6 pm (Fig. 3). At the mid T-POD the highest rate was seen around 4–5 pm, and the lowest around 5–6 am (Fig. 3). At the inner T-POD, highest detection rates were seen around 100 mins after high tide (Fig. 3). At the mid T-POD, detection rates were highest around low tide, and at the outer T-POD around high tide (Fig. 3). Wind direction had the overall effect of increased DPM per hour during northerly winds and decreased during southerly winds (Fig. 4). Detection rates tended to decrease with increasing wind speed (Fig. 4).

Table 6
Index of relative importance (IRI), estimated degrees of freedom (edf) and significance (*p*-value) for the parametric (first 3 rows) and smoothed terms in the top model in the DPM per day dataset. Bold terms are significant at the 5% level. *The first three rows of 'edf' are coefficient estimates for the parametric terms.

Term	IRI	edf	p-value
Intercept	**1**	**2.71***	**< 2e-16**
TPOD2	**1**	**0.57***	**5.86e-4**
TPOD3	**1**	**1.07***	**1.32e-6**
ti(DPMt-1):TPOD1	**1**	**2.56**	**0.001**
ti(DPMt-1):TPOD2	**1**	**1.00**	**0.008**
ti(DPMt-1):TPOD3	1	1.00	0.174
ti(Wspd):TPOD1	**1**	**1.00**	**0.006**
ti(Wspd):TPOD2	**1**	**1.00**	**0.012**
ti(Wspd):TPOD3	1	1.00	0.446
ti(Wdir):TPOD1	**0.9**	**1.78**	**0.006**
ti(Wdir):TPOD2	0.9	0.00	0.387
ti(Wdir):TPOD3	0.9	1.17	0.059
ti(PPM):TPOD1	0.49	1.00	0.062
ti(PPM):TPOD2	0.49	1.00	0.104
ti(PPM):TPOD3	0.49	1.00	0.486

4. Discussion

4.1. Pile-driving and the effect on dolphin detections

Multi-model inference revealed that the top models contained at least one piling-related variable, indicating that pile-driving influenced detection rates of Hector's dolphins in Lyttelton Harbour. Considering that several studies of harbour porpoise have shown that animal density is correlated to the number of acoustic detections (Marques et al., 2009; Sveegaard et al., 2011; Kyhn et al., 2012; Dähne et al., 2013), we propose that this is the most parsimonious explanation for differences in detection rates of Hector's dolphins also. DPM per day decreased at the inner T-POD, as piling (PPM) increased, while it increased at the mid-harbour T-POD. The mid harbour location is further from the piling activity, and is partially shielded by Sticking Point (Fig. 1). Average broadband sound levels were 14 dB lower at the mid-harbour T-POD (Table 1, see Leunissen and Dawson, 2018 for more detail). Taken together, these data suggest that dolphins displaced from the inner harbour moved towards the mid harbour area, increasing the chance they were detected by the mid T-POD. This effect was also observed visually in a study of impact of pile-driving from offshore wind farm construction on harbour porpoise (Dähne et al., 2013). The lack of strong trends for piling related variables at the outer T-POD indicates this detector was outside the zone of impact and, thus, provides an outer boundary.

Table 5
Results of model selection for GAMs with DPM per day as the response variable. Only models within 6 AICc points of the top model are shown. Rank is based on AICc, 'Wt' is the Akaike weight of the model, '% DE' is the percentage deviance explained by the model, R^2 is the adjusted r-squared value, and the 'Model' column shows the model structure. Terms enclosed by 's()' are smoothed variables, and by 'ti()' are smoothed seperately for each T-POD location.

Rank	Model	df	AICc	ΔAICc	Wt	% DE	R^2
1	T-POD + ti(DPMt-1) + ti(Wspd) + ti(Wdir) + ti(PPM)	18.9	1746.92	0	0.49	44.2	0.48
2	T-POD + ti(DPMt-1) + ti(Wspd) + ti(Wdir)	15.6	1747.25	0.33	0.41	42.2	0.48
3	T-POD + ti(DPMt-1) + ti(Wspd)	12	1750.06	3.13	0.1	39.3	0.443

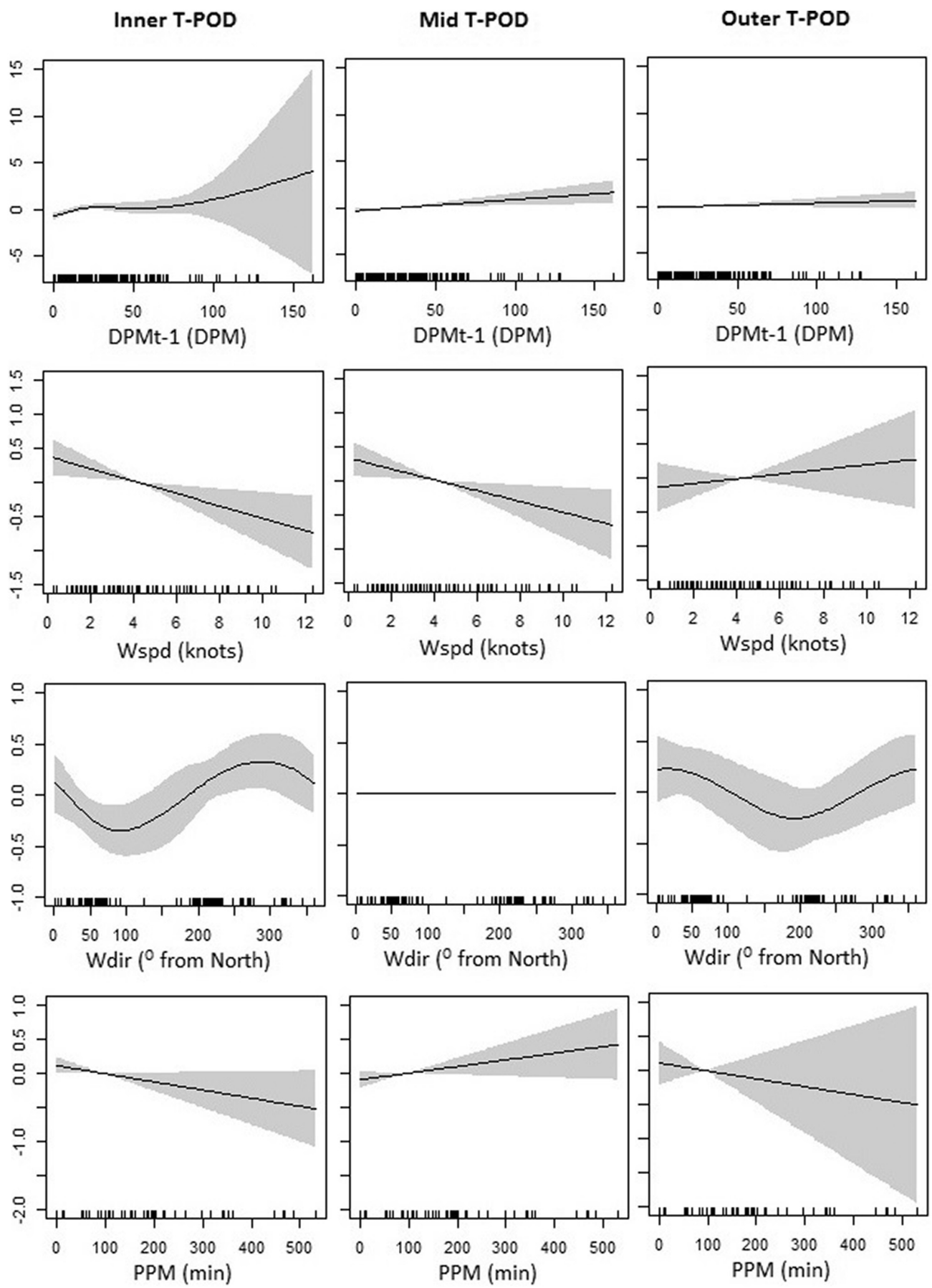

Fig. 2. The predicted smoothing functions for each explanatory variable, from the highest ranked model in which it appears, and its effect on DPM per day (y-axis) with shaded 95% confidence intervals. The ticks along the bottom edge of the plot indicate the values found in the measured data for that variable.

Table 7
Results of model selection for GAMs with DPM per hour as the response variable. Only models within 6 AICc points of the top model are shown. Rank is based on AICc, 'Wt' is the Akaike weight of the model, '% DE' is the percentage deviance explained by the model, R^2 is the adjusted r-squared value, and the 'Model' column shows the model structure. Terms enclosed by 's()' are smoothed variables, and by 'ti()' are smoothed seperately for each T-POD location, except the term 'ti (TSP,Dur)' which is an interaction between the 2 variables.

Rank	Model	df	AICc	Δ	Wt	% DE	R^2 (adj.)
1	ti(DPMt-1) + TPOD + ti(Hour) + ti(TSP) + ti(SEL) + ti(tide) + ti(TSP,Dur) + ti(Wdir) + s(Dur)	46.4	10,491.1	0	0.46	19.3	0.152
2	ti(DPMt-1) + TPOD + ti(Hour) + ti(TSP) + ti(SEL) + ti(tide) + ti(TSP,Dur) + ti(Wdir)	43.05	10,492.2	1.1	0.27	19.1	0.152
3	ti(DPMt-1) + TPOD + ti(Hour) + ti(TSP) + ti(SEL) + ti(tide) + ti(TSP,Dur) + ti(Dur)	41.66	10,494.6	3.5	0.08	19.1	0.148
4	ti(DPMt-1) + TPOD + ti(Hour) + ti(TSP) + ti(SEL) + ti(tide) + ti(TSP,Dur) + ti(Wspd)	43.99	10,494.8	3.7	0.07	18.9	0.148
5	ti(DPMt-1) + TPOD + ti(Hour) + ti(TSP) + ti(SEL) + ti(tide) + ti(TSP,Dur)	40.8	10,495.6	4.5	0.05	18.8	0.148
6	ti(DPMt-1) + TPOD + ti(Hour) + ti(TSP) + ti(SEL) + ti(tide) + ti(Wdir) + s(Dur)	42.75	10,496.1	5.0	0.04	18.9	0.158
7	ti(DPMt-1) + TPOD + ti(Hour) + ti(TSP) + ti(SEL) + ti(tide) + ti(Wdir)	39.54	10,496.4	5.3	0.03	18.7	0.157

Table 8
Index of relative importance (IRI), estimated degrees of freedom (edf) and significance (p-value) of each term in the top model (except for s(Wspd) - values are from 4th best model) for the parametric (first 3 rows) and smoothed terms in the DPM per hour dataset. Bold terms are significant at the 5% level. *The first three rows of 'edf' are coefficient estimates for the parametric terms.

Term	IRI	edf	p-value
Intercept	**1**	**−0.84***	**< 2e-16**
TPOD2	**1**	**0.97***	**< 2e-16**
TPOD3	**1**	**1.28***	**< 2e-16**
ti(DPMt-1):TPOD1	**1**	**3.01**	**< 2e-16**
ti(DPMt-1):TPOD2	**1**	**2.31**	**9.74e-08**
ti(DPMt-1):TPOD3	**1**	**2.26**	**1.54e-04**
ti(TSP):TPOD1	**1**	**3.57**	**2.58e-05**
ti(TSP):TPOD2	1	1.00	0.132
ti(TSP):TPOD3	1	1.75	0.355
ti(Hour):TPOD1	**1**	**2.82**	**8.18e-05**
ti(Hour):TPOD2	**1**	**1.98**	**0.001**
ti(Hour):TPOD3	1	0.00	0.643
ti(SEL):TPOD1	**1**	**2.48**	**0.034**
ti(SEL):TPOD2	1	1.00	0.129
ti(SEL):TPOD3	1	1.46	0.098
ti(tide):TPOD1	**1**	**1.66**	**0.019**
ti(tide):TPOD2	1	0.96	0.157
ti(tide):TPOD3	**1**	**1.86**	**0.005**
ti(TSP,Dur)	**0.93**	**3.04**	**0.045**
s(Wdir)	**0.8**	**1.72**	**0.013**
s(Dur)	0.57	2.96	0.185
s(Wspd)	0.08	1.00	0.057

This is reinforced by the low noise contours at this location in Leunissen and Dawson (2018).

The greater temporal resolution of the DPM per hour response variable supported a more nuanced analysis, indicating that time-since-piling, piling SEL and the interaction of time-since-piling and duration were significant influences. Here also, responses were often location specific. DPM per hour at the inner harbour T-POD decreased significantly with increasing SEL (Fig. 3) indicating that it was not only the presence of pile-driving but also its intensity that led to avoidance reactions. This is probably why studies assessing the impact of windfarm construction on harbour porpoise see avoidance reactions at much larger distances (around 20 km; Tougaard et al., 2009; Brandt et al., 2011; Dähne et al., 2013). Pile-driving for windfarms involves much larger piles (around 2.4–4 m diameter, compared to 0.61–0.71 m in Lyttelton) and correspondingly heavier pile drivers, leading to much higher sound source levels (Fricke and Rolfes, 2015). Also, the harder substrate found in these offshore locations (sand/gravel, compared to the fluid mud layer in Lyttelton) allows the sound to propagate further (due to increased reflection from the bottom surface; Jensen et al., 2011). This effect on propagation leads to an increase in range at which the sound can be heard.

4.2. Duration of impact

Analysis of DPM per hour suggested that the decreasing trend in detection rate following a pile-driving event lasted around 33 h. Detection rate restored to the level of the hour prior to exposure after 83 h. This gradual increase in detections after 33 h probably reflected the gradual return of dolphins to the inner harbour following a pile-driving event. Levelling-off of the trend in detection rate with time-since-piling (as in Brandt et al., 2011) indicates that the previous piling event no longer has an effect on detection rate. This was observed in the current study at 83 h. The modelled decline in DPM (see Figs. 3 and 5) after that point was not well supported by data (only during the Christmas/New year break did time-since-piling exceed 90 h). The maximum duration of effect on detections (83 h) is comparable to, though slightly longer than, the longest duration of effect estimated for the impact of pile-driving on harbour porpoise (72 h; Brandt et al., 2011). It is interesting that the lowest detection rate did not occur immediately after pile-driving, but rather 33 h later. This seems counterintuitive and is not observed in other studies (e.g. Tougaard et al., 2009; Brandt et al., 2011), but could have been driven by a need to stay in the area for foraging opportunities, for example. Another reason for this delayed minimum could be due to lower SEL in this study. Louder sounds are more likely to result in an immediate impact, while quieter sounds could be tolerated for longer before a threshold is reached.

DPM per hour decreased with duration of the previous pile-driving event up to a duration of 150 mins, although the effect was not strong. There was however an important interaction between time-since-piling and duration of the previous piling event. For long duration piling events, the decrease in DPM per hour persisted for longer after piling had finished.

4.3. Influence of other factors

T-POD location was the most significant influence on detection rate of Hector's dolphins in Lyttelton Harbour (Table 8). Similar fine-scale variation in spatial distribution of Hector's dolphin has previously been revealed by other acoustic (e.g. Dawson et al., 2013), and visual surveys (e.g. Brough et al., 2018). Decreased hourly detections at the inner T-POD between 7 am and 4 pm could be due to disturbance by higher levels of vessel traffic near the wharf and construction activity during working hours (e.g. increased swimming speed in killer whales with increased boat traffic, following a diurnal pattern (Kruse, 1998)). Another explanation could be diel movements of prey (as observed with harbour porpoise; Todd et al., 2009). The changes in detections in response to time of day are in addition to the changes following pile-driving events (accounted for by the model structure). Since we were unable to acquire true control data, however, it cannot be concluded that Hector's dolphin detections would follow the same daily trend outside the monitoring period, with no construction activities taking place. Diurnal variation in Hector's dolphin habitat use has previously been observed in Porpoise Bay (Bejder and Dawson, 2001) and Akaroa

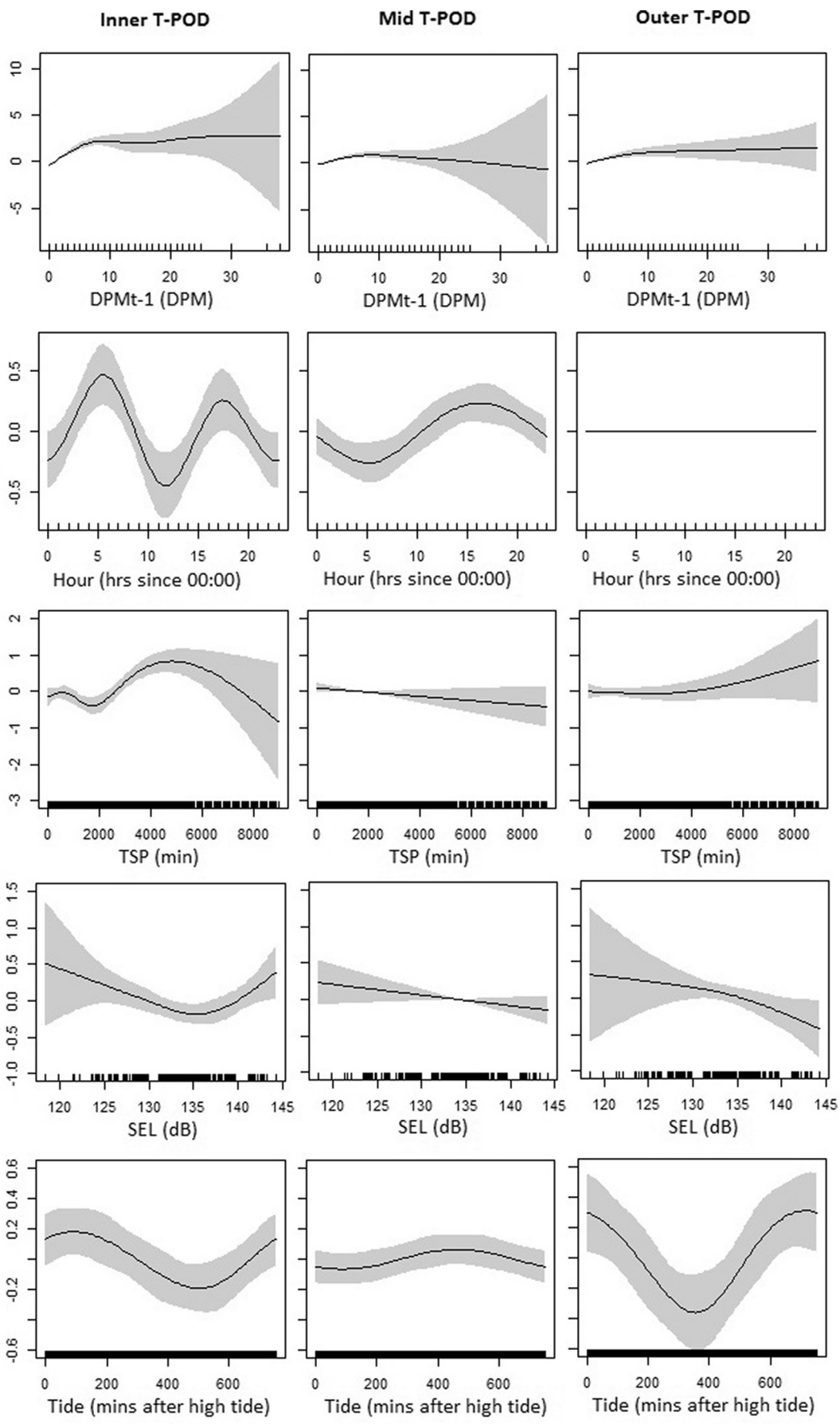

Fig. 3. The predicted smoothing functions for each explanatory variable and its effect on DPM per hour (y-axis) with shaded 95% confidence intervals. The ticks along the bottom edge of the plot indicate the values found in the measured data for that variable.

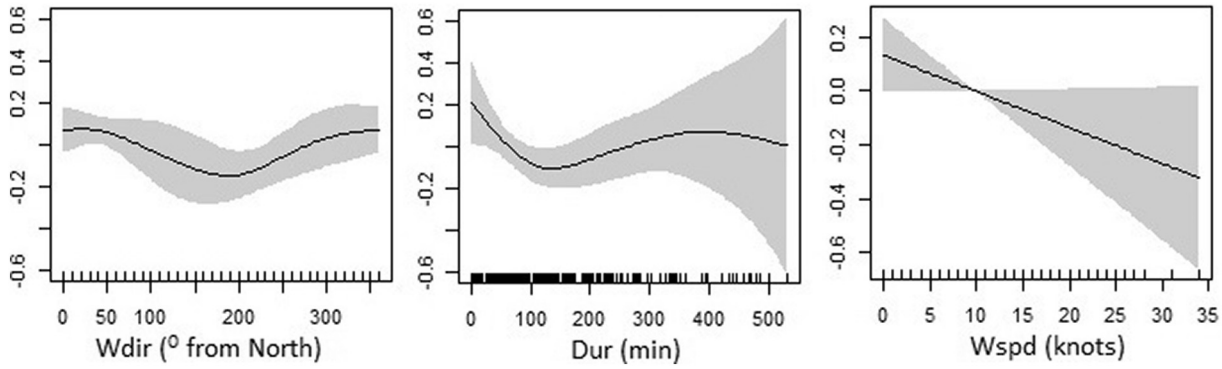

Fig. 4. The predicted smoothing functions for the explanatory variable and its effect on DPM per hour at all T-POD locations (y-axis) with shaded 95% confidence intervals. The ticks along the bottom edge of the plot indicate the values found in the measured data for that variable.

Harbour (Dawson et al., 2013), but does not follow the same trend as observed in this study.

State of the tide also had a significant effect on Hector's dolphin distribution in nearby Akaroa Harbour (Dawson et al., 2013). Furthermore, detection rates of bottlenose dolphins on the coast of Scotland (Mendes et al., 2002), and harbour porpoise in the Bay of Fundy (Johnston et al., 2005) were correlated with tidal state. A possible driver for the variation in dolphin distribution is the tidally mediated movement of prey species. For example, yellow-eyed mullet (*Aldrichetta forsteri*), identified as a prey species from Hector's dolphin stomach contents (Miller et al., 2012), was most often caught at night time low tides in Manukau Harbour, northern New Zealand (Morrison et al., 2002).

At least at the inner and middle T-POD locations, more dolphin detections were made at lower wind speeds. This was possibly due to higher attenuation of click sounds during high wind speeds in shallow water, caused by the increased amount of air bubbles in the water and less reflection at the ruffled water surface (Norton and Novarini, 1996). In contrast, Brandt et al. (2016) observed the opposite effect of wind on detections of harbour porpoise. This effect was determined to be due to the increased propagation of piling noise at lower wind speeds, leading to lower detection rates. In addition, more noise clicks were recorded at higher wind speeds due to increased levels of ambient noise giving false-positive detections (Brandt et al., 2016).

4.4. Temporary threshold shift (TTS) in hearing

This study showed that pile-driving noise clearly influenced Hector's dolphin distribution. Another important impact from the noise is increased risk of hearing damage, particularly close to the piling activity. Leunissen and Dawson (2018) calculated zones of potential impact in Lyttelton Harbour based on hearing studies of harbour porpoise (Kastelein et al., 2013a; Kastelein et al., 2013b; Kastelein et al., 2015). These zones depend on the length of time they spend near the pile-driving. While these zones did not cover very large areas, Hector's dolphins may tolerate noise at levels which could induce TTS if there was a sufficient reward for doing so. Hector's dolphins have been observed inside the zones where they are at risk of TTS. We visually observed dolphins (near our close-range sound recorder moored about 370 m from the piling activity) and, thus, have many recordings of their clicks (up to 10 consecutive dolphin positive minutes) during pile-driving events. Masking of environmental sounds is highly likely in the inner harbour. The spatial extent of these impacts into the outer harbour was heavily reduced due to the shielding effect of the breakwater at Sticking Point (Leunissen and Dawson, 2018).

The sensitivity of Hector's dolphin hearing has not yet been tested, so the TTS calculations by Leunissen and Dawson (2018) assumed that it is similar to that of harbour porpoise. Two lines of evidence suggest that Hector's dolphin hearing might be significantly more sensitive. First, the source level of Hector's dolphin echolocation clicks is much lower than that of harbour porpoises (Kyhn et al., 2009), implying that to serve the same function the receiver system should be more sensitive. Second, we detected behavioural change in Hector's dolphins at SELs lower than those which have been observed to modify behaviour of harbour porpoise (Tougaard et al., 2009; Bailey et al., 2010; Brandt et al., 2011; Dähne et al., 2013; Kastelein et al., 2013b).

In summary, pile-driving noise was associated with a decrease in detection rate of Hectors' dolphins at the inner T-POD, with an increase

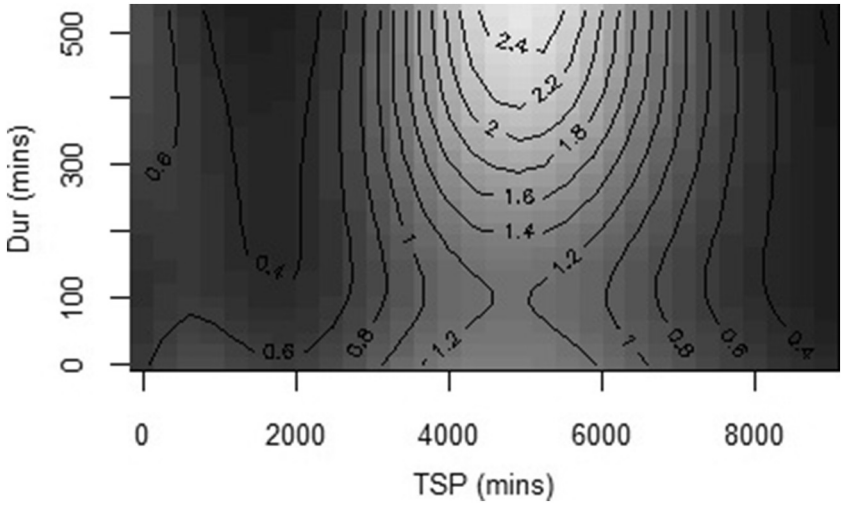

Fig. 5. Interaction between time-since-piling (TSP) and Duration-of-piling (Dur) calculated in the top model, with contours showing the predicted DPM per hour at the inner TPOD when the other variables are fixed as follows: "Hour" = 16 (4 pm), "Wdir" = 50° from North, "tide" = 100 mins after high tide, "SEL" = 134 dB, "DPMt-1" = 1.1 mins.

in detections per day seen at the mid T-POD. The most parsimonious explanation is that this was driven by dolphins moving from the inner harbour to the mid harbour when pile-driving was underway. Reduced density of dolphins near the inner T-POD was also implied by decreasing detection rates following a bout of piling, restoring to pre-piling levels after 50–83 h. Intensity of piling also affected detection rate, with fewer detections in the inner harbour on days with longer duration piling activity, and fewer detections per hour after longer and louder piling events. Pile-driving has also been shown to introduce a risk of TTS (Leunissen and Dawson, 2018).

We have demonstrated that pile-driving had an effect on Hector's dolphins's use of Lyttelton Harbour. While the population level effect is uncertain, the extra energy expenditure from area abandonment and reduced foraging opportunities are potentially very important in the context of the endangered status of this species, and in addition to the other threats it faces. It is essential that future research strives to quantify the population level impacts. In the meantime, society should take a precautionary approach to such impacts, taking whatever means possible to reduce the likelihood of detrimental change.

There are options to mitigate the noise-related effects of pile-driving. For example, bubble curtains can significantly reduce the noise radiated into the water column (Lucke et al., 2011; Nehls et al., 2016; Tsouvalas and Metrikine, 2016) particularly when confined (e.g. Buehler et al., 2015). For Lyttelton Harbour, however, significant re-suspension of sediment could breach a condition of the Coastal Permit, and therefore makes bubble curtains an unlikely noise-mitigation option for future construction work. A strategy for reducing noise pollution could be to employ screw-piling technology, rather than impact pile-driving, which produces significantly less underwater noise (Saleem, 2011). Since Hector's dolphins are generally found closer inshore during the summer (Rayment et al., 2010; Brough et al., 2014, 2018), restricting piling to winter time would also likely reduce its impact.

Declarations of interest

None.

Acknowledgements

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Appendix A

Temporal autocorrelation

Two methods were used to reduce temporal auto-correlation in both datasets, tested using the *acf* function in R. The use of the DPMt-1 variable in the models (Tables 2 and 3) was much more effective in reducing temporal auto-correlation in model residuals than using a corAR1 correlation structure, in both datasets (Figs. A.1 and A.2).

DPM per hour

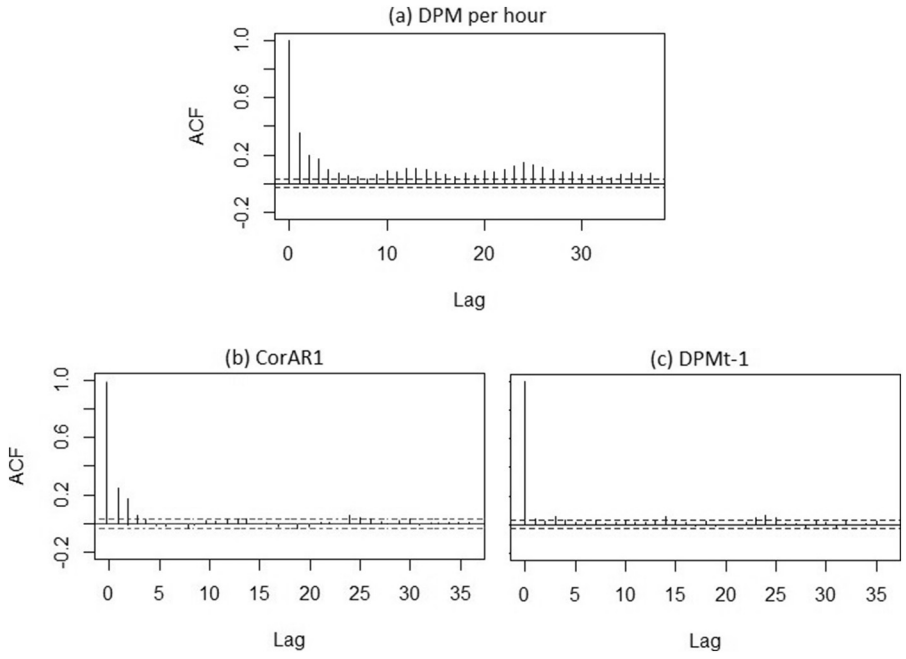

Fig. A.1. (a): Temporal autocorrelation of the DPM per hour variable; (b): Temporal autocorrelation of the residuals of the top model, with the corAR1 correlation structure, of DPM per hour; (c): Temporal autocorrelation of the residuals of the top model, with the DPMt-1 variable, of DPM per hour. Horizontal dotted lines indicate the 95% confidence interval of white noise of this series.

DPM per day

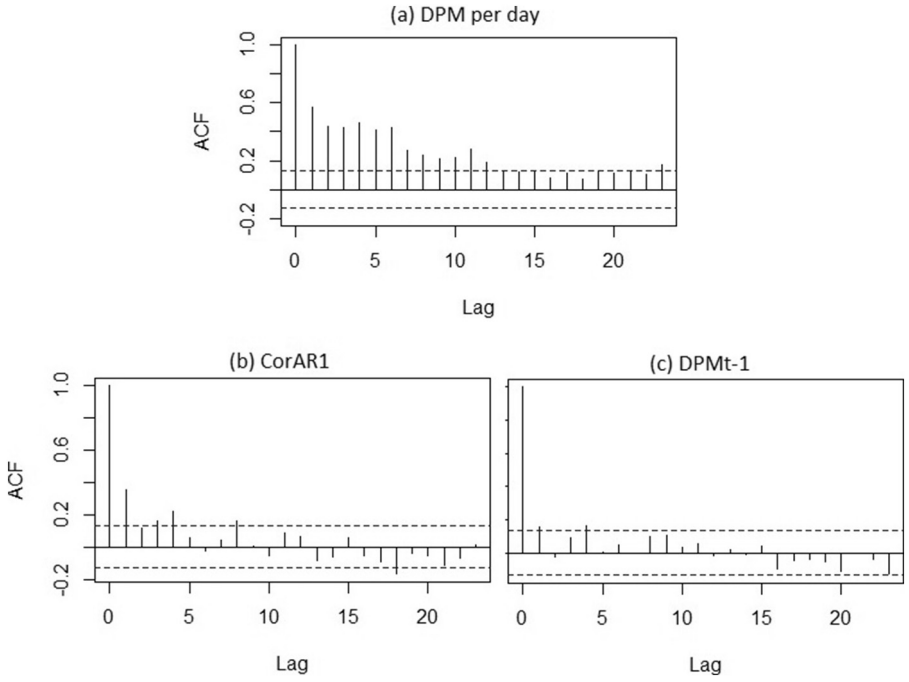

Fig. A.2. (a): Temporal autocorrelation of the DPM per day variable; (b): Temporal autocorrelation of the residuals of the top model, with the corAR1 correlation structure, of DPM per day; (c): Temporal autocorrelation of the residuals of the top model, with the DPMt-1 variable, of DPM per day. Horizontal dotted lines indicate the 95% confidence interval of white noise of this series.

References

Aguilar Soto, N., Johnson, M., Madsen, P.T., Tyack, P.L., Bocconcelli, A., Fabrizio Borsani, J., 2006. Does intense ship noise disrupt foraging in deep-diving cuvier's beaked whales (Ziphius cavirostris)? Mar. Mammal Sci. 22, 690–699. https://doi.org/10.1111/j.1748-7692.2006.00044.x.

Anderson, D., Burnham, K., Thompson, W., 2000. Null hypothesis testing: problems, prevalence, and an alternative. J. Wildl. Manag. 64, 912–923. https://doi.org/10.2307/1130851.

Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G., Thompson, P.M., 2010. Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals. Mar. Pollut. Bull. 60, 888–897. https://doi.org/10.1016/j.marpolbul.2010.01.003.

Bejder, L., Dawson, S., 2001. Abundance, residency, and habitat utilisation of Hector's dolphins (Cephalorhynchus hectori) in Porpoise Bay, New Zealand. New Zeal. J. Mar. Freshw. Res. 35, 277–287. https://doi.org/10.1080/00288330.2001.9516998.

Brandt, M.J., Diederichs, A., Betke, K., Nehls, G., 2011. Responses of harbour porpoises to pile-driving at the Horns Rev II offshore wind farm in the Danish North Sea. Mar. Ecol. Prog. Ser. 421, 205–216. https://doi.org/10.3354/meps08888.

Brandt, M.J., Dragon, A.-C., Diederichs, A., Schubert, A., Kosarev, V., Nehls, G., 2016. Effects of Offshore Pile-Driving on Harbour Porpoise Abundance in the German Bight. BioConsult SH GmbH & Co KG, pp. 246. https://www.offshore-stiftung.de/sites/offshorelink.de/files/documents/Study_Effects%20of%20offshore%20pile%20driving%20on%20harbour%20porpoise%20abundance%20in%20the%20German%20Bight_0.pdf>.

Brough, T., Slooten, E., Dawson, S., 2014. Marine Mammals and the Port Lyttelton Development: an Environmental Impact Assessment. University of Otago, Department of Marine Science, pp. 41.

Brough, T., Rayment, W., Slooten, E., Dawson, S., 2018. Fine scale distribution for a population of New Zealand's only endemic dolphin (*Cephalorhynchus hectori*) shows long-term stability of coastal hotspots. Marine Mammal Science 35, 140–163. https://doi.org/10.1111/mms.12528.

Brough T., Rayment, W., Slooten, E., Dawon, S., (in press). The spatiotemporal distribution of foraging in a marine predator: behavioural drivers of hotspot formation, Mar. Ecol. Prog. Ser.

Buehler, D., Oestman, R., Reyff, J., Pommerenck, K., Mitchell, B., 2015. Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile-Driving on Fish. Report No. CTHWANP-RT-15-306.01.01. Division of Environmental Analysis, California Department of Transportation.

Burnham, K.P., Anderson, D.R., 2002. Model selection and multimodel inference: a practical information-theoretic approach. In: Ecological Modelling, 2nd ed. pp. 149–169. https://doi.org/10.1016/j.ecolmodel.2003.11.004.

Carstensen, J., Henriksen, O.D., Teilmann, J., 2006. Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). Mar. Ecol. Prog. Ser. 321, 295–308. https://doi.org/10.3354/meps321295.

Castellote, M., Clark, C.W., Lammers, M.O., 2012. Acoustic and behavioural changes by fin whales (Balaenoptera physalus) in response to shipping and airgun noise. Biol. Conserv. 147, 115–122. https://doi.org/10.1016/j.biocon.2011.12.021.

Dähne, M., Verfuß, U.K., Diederics, A., Meding, A., Benke, A., 2006. T-pod test tank calibration and field calibration. In: Proceedings of the Workshop: Static Acoustic Monitoring of Cetaceans, Held at the 20th Annual Meeting of the European Cetacean Society, Gdynia, Poland, 2nd April 2006, pp. 34–36 Gdynia.

Dähne, M., Gilles, A., Lucke, K., Peschko, V., Adler, S., Krügel, K., Sundermeyer, J., Siebert, U., 2013. Effects of pile-driving on harbour porpoises (Phocoena phocoena) at the first offshore wind farm in Germany. Environ. Res. Lett. 8, 16. https://doi.org/10.1088/1748-9326/8/2/025002.

Dawson, S.M., 2018. Cephalorhynchus dolphins. In: Perrin, W.F., Würsig, B., Thewissen, J.G.M. (Eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, pp. 166–172.

Dawson, S.M., Thorpe, C.W., 1990. A quantitative-analysis of the sounds of hector dolphin. Ethology 86, 131–145.

Dawson, S., Fletcher, D., Slooten, E., 2013. Habitat use and conservation of an endangered dolphin. Endanger. Species Res. 21, 45–54. https://doi.org/10.3354/esr00508.

Degraer, S., Brabant, R., Rumes, B., Degraer Brabant, R., Rumes, B.S., 2012. Offshore Wind Farms in the Belgian Part of the North Sea: Heading for an Understanding of Environmental Impacts. Royal Belgian institute of natural sciences, management unit of the North Sea mathematical models, Marine ecosystem management unit (MUMM) (155 pp. + annexes).

Ferguson, M.C., Barlow, J., Reilly, S.B., Gerrodette, T., 2005. Predicting Cuvier's (Ziphius cavirostris) and Mesoplodon beaked whale population density from habitat characteristics in the eastern tropical Pacific Ocean. J. Cetacean Res. Manag. 7, 287.

Fernández, A., Edwards, J.F., Rodriguez, F., De Los Monteros, A.E., Herraez, P., Castro, P., Jaber, J.R., Martin, V., Arbelo, M., 2005. "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (Family Ziphiidae) exposed to anthropogenic sonar signals. Vet. Pathol. 42, 446–457.

Filadelfo, R., Mintz, J., Michlovich, E., D'Amico, A., Tyack, P.L., Ketten, D.R., 2009. Correlating military sonar use with beaked whale mass strandings: what do the historical data show? Aquat. Mamm. 35, 435–444. https://doi.org/10.1578/AM.35.4.2009.435.

Fricke, M.B., Rolfes, R., 2015. Towards a complete physically based forecast model for underwater noise related to impact pile-driving. J. Acoust. Soc. Am. 137, 1564–1575. https://doi.org/10.1121/1.4908241.

Gray, H., van Waerebeek, K., 2011. Postural instability and akinesia in a pantropical spotted dolphin, Stenella attenuata, in proximity to operating airguns of a geophysical seismic vessel. J. Nat. Conserv. 19, 363–367. https://doi.org/10.1016/j.jnc.2011.06.005.

Hastie, T.J., Tibshirani, R.J., 1990. Generalized Additive Models. Chapman and Hall/CRC, Florida.

Jensen, F.B., Kuperman, W.A., Porter, M.B., Schmidt, H., 2011. Computational Ocean Acoustics. Springer Science & Business Media.

Johnston, D.W., Westgate, A.J., Read, A.J., 2005. Effects of fine-scale oceanographic features on the distribution and movements of harbour porpoises Phocoena phocoena in the Bay of Fundy. Mar. Ecol. Prog. Ser. 295, 279–293.
Kastelein, R.A., Hoek, L., Gransier, R., de Jong, C.A.F., 2013a. Hearing thresholds of a harbor porpoise (Phocoena phocoena) for playbacks of multiple pile-driving strike sounds. J. Acoust. Soc. Am. 134, 2302–2306. https://doi.org/10.1121/1.4817842.
Kastelein, R.A., van Heerden, D., Gransier, R., Hoek, L., 2013b. Behavioral responses of a harbor porpoise (Phocoena phocoena) to playbacks of broadband pile-driving sounds. Mar. Environ. Res. 92, 206–214. https://doi.org/10.1016/j.marenvres.2013.09.020.
Kastelein, R.A., Gransier, R., Marijt, M.A.T., Hoek, L., 2015. Hearing frequency thresholds of harbor porpoises (Phocoena phocoena) temporarily affected by played back offshore pile-driving sounds. J. Acoust. Soc. Am. 137, 556–564. https://doi.org/10.1121/1.4906261.
Kruse, S., 1998. The interaction between killer whales and boats in Johnstone Strait, B.C. In: Dolphin Societies Discoveries and Puzzles, pp. 149–159.
Kyhn, L.A., Tougaard, J., Jensen, F., Wahlberg, M., Stone, G., Yoshinaga, A., Beedholm, K., Madsen, P.T., 2009. Feeding at a high pitch: source parameters of narrow band, high-frequency clicks from echolocating off-shore hourglass dolphins and coastal Hector's dolphins. J. Acoust. Soc. Am. 125, 1783–1791. https://doi.org/10.1121/1.3075600.
Kyhn, L.A., Tougaard, J., Thomas, L., Duve, L.R., Stenback, J., Amundin, M., Desportes, G., Teilmann, J., 2012. From echolocation clicks to animal density—acoustic sampling of harbor porpoises with static dataloggers. J. Acoust. Soc. Am. 131, 550–560. https://doi.org/10.1121/1.3662070.
Leunissen, E.M., Dawson, S.M., 2018. Underwater noise levels of pile-driving in a New Zealand harbour, and the potential impacts on endangered Hector's dolphins. Mar. Pollut. Bull. 135, 195–204. https://doi.org/10.1016/j.marpolbul.2018.07.024.
Lucke, K., Siebert, U., Lepper, P.A., Blanchet, M.-A., 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (Phocoena phocoena) after exposure to seismic airgun stimuli. J. Acoust. Soc. Am. 125, 4060–4070. https://doi.org/10.1121/1.3117443.
Lucke, K., Lepper, P.A., Blanchet, M.-A., Siebert, U., 2011. The use of an air bubble curtain to reduce the received sound levels for harbor porpoises (*Phocoena phocoena*). J. Acoust. Soc. Am. 130 (5), 3406–3412. https://doi.org/10.1121/1.3626123.
Madsen, P.T., Wahlberg, M., Tougaard, J., Lucke, K., Tyack, P.L., 2006. Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Mar. Ecol. Prog. Ser. 309, 279–295. https://doi.org/10.3354/meps309279.
Mallock, A., 1910. The damping of sound by frothy liquids. Proc. R. Soc. London. Ser. A 84, 391–395.
Marques, T.A., Thomas, L., Ward, J., DiMarzio, N., Tyack, P.L., 2009. Estimating cetacean population density using fixed passive acoustic sensors: an example with Blainville's beaked whales. J. Acoust. Soc. Am. 125, 1982–1994. https://doi.org/10.1121/1.3089590.
McDonald, M.A., Hildebrand, J.A., Wiggins, S.M., Ross, D., 2008. A 50 year comparison of ambient ocean noise near San Clemente Island: a bathymetrically complex coastal region off Southern California. J. Acoust. Soc. Am. 124, 1985–1992.
Mendes, S., Turrell, W., Lütkebohle, T., Thompson, P., 2002. Influence of the tidal cycle and a tidal intrusion front on the spatio-temporal distribution of coastal bottlenose dolphins. Mar. Ecol. Prog. Ser. 239, 221–229.
Miller, E., Lalas, C., Dawson, S., Ratz, H., Slooten, E., 2012. Hector's dolphin diet: the species, sizes and relative importance of prey eaten by Cephalorhynchus hectori, investigated using stomach content analysis. Mar. Mamm. Sci. https://doi.org/10.1111/j.1748-7692.2012.00594.x.
Morrison, M.A., Francis, M.P., Hartill, B.W., Parkinson, D.M., 2002. Diurnal and tidal variation in the abundance of the fish fauna of a temperate tidal mudflat. Estuar. Coast. Shelf Sci. 54, 793–807.
Nehls, G., Rose, A., Diederichs, A., Bellmann, M., Pehlke, H., 2016. Noise mitigation during pile-driving efficiently reduces disturbance of marine mammals. In: The Effects of Noise on Aquatic Life II. Springer, pp. 755–762.
Norton, G.V., Novarini, J.C., 1996. The effect of sea-surface roughness on shallow water waveguide propagation: a coherent approach. J. Acoust. Soc. Am. 99, 2013. https://doi.org/10.1121/1.415388.
Paiva, E.G., Salgado Kent, C.P., Gagnon, M.M., McCauley, R., Finn, H., 2015. Reduced detection of Indo-Pacific bottlenose dolphins (Tursiops aduncus) in an inner harbour channel during pile-driving activities. Aquat. Mamm. 41, 455–468. https://doi.org/10.1578/AM.41.4.2015.455.
Philpott, E., Englund, A., Ingram, S., Rogan, E., 2007. Using T-PODs to investigate the echolocation of coastal bottlenose dolphins. J. Mar. Biol. Assoc. United Kingdom 87, 11–17. https://doi.org/10.1017/S002531540705494X.
Rayment, W., Dawson, S., Slooten, E., Bräger, S., Fresne, S.D., Webster, T., 2009a. Kernel density estimates of alongshore home range of Hector's dolphins at Banks Peninsula, New Zealand. Mar. Mamm. Sci. 25 (3), 537–556.
Rayment, W., Dawson, S., Slooten, L., 2009b. Trialling an automated passive acoustic detector (T-POD) with hector's dolphins (Cephalorhynchus hectori). J. Mar. Biol. Assoc. United Kingdom 89, 1015–1022. https://doi.org/10.1017/S0025315409003129.
Rayment, W., Dawson, S., Slooten, E., 2010. Seasonal changes in distribution of Hector's dolphin at Banks Peninsula, New Zealand: implications for protected area design. Aquat. Conserv. 20, 106–116.
Rayment, W., Dawson, S., Scali, S., Slooten, L., 2011. Listening for a needle in a haystack: passive acoustic detection of dolphins at very low densities. Endanger. Species Res. 14, 149–156. https://doi.org/10.3354/esr00356.
Rolland, R.M., Parks, S.E., Hunt, K.E., Castellote, M., Corkeron, P.J., Nowacek, D.P., Wasser, S.K., Kraus, S.D., 2012. Evidence that ship noise increases stress in right whales. Proc. R. Soc. B Biol. Sci. 279, 2363–2368. https://doi.org/10.1098/rspb.2011.2429.
Romano, T.A., Keogh, M.J., Kelly, C., Feng, P., Berk, L., Schlundt, C.E., Carder, D.A., Finneran, J.J., 2004. Anthropogenic sound and marine mammal health: measures of the nervous and immune systems before and after intense sound exposure. Can. J. Fish. Aquat. Sci. 61, 1124–1134. https://doi.org/10.1139/f04-055.
Saleem, Z., 2011. Alternatives and Modifications of Monopile Foundation or Its Installation Technique for Noise Mitigation. Report by. Delft University of Technology for Stichting De Noordzee (the North Sea Foundation), Delft, pp. 68. www.vliz.be/imisdocs/publications/223688.pdf.
Slooten, E., Dawson, S.M., 2010. Assessing the effectiveness of conservation management decisions: likely effects of new protection measures for Hector's dolphin (Cephalorhynchus hectori). Aquat. Conserv. Mar. Freshwat. Ecosyst. 20 (3), 334–347.
Sveegaard, S., Teilmann, J., Berggren, P., Mouritsen, K.N., Gillespie, D., Tougaard, J., 2011. Acoustic surveys confirm the high-density areas of harbour porpoises found by satellite tracking. ICES J. Mar. Sci. 68, 929–936. https://doi.org/10.1093/icesjms/fsr025.
Thompson, P.M., Lusseau, D., Barton, T., Simmons, D., Rusin, J., Bailey, H., 2010. Assessing the responses of coastal cetaceans to the construction of offshore wind turbines. Mar. Pollut. Bull. 60, 1200–1208. https://doi.org/10.1016/j.marpolbul.2010.03.030.
Thomsen, F., Elk, N. van, Brock, V., Piper, W., 2005. On the performance of automated porpoise-click-detectors in experiments with captive harbor porpoises (Phocoena phocoena). J. Acoust. Soc. Am. 118, 37–40. https://doi.org/10.1121/1.1937347.
Todd, V.L., Todd, I., Lepper, P.A., Tregenza, N.C., 2009. Echolocation activity of harbour porpoises (Phocoena Phocoena) around an offshore gas-production platform-drilling-rig complex. Proc. Inst. Acoust. 31, 219–226.
Torres, L.G., Read, A.J., Halpin, P., 2008. Fine-scale habitat modeling of a top marine predator: do prey data improve predictive capacity? Ecol. Appl. 18 (1720–1717).
Tougaard, J., Carstensen, J., Teilmann, J., Skov, H., Rasmussen, P., 2009. Pile-driving zone of responsiveness extends beyond 20 km for harbor porpoises (Phocoena phocoena (L.)). J. Acoust. Soc. Am. 126, 11–14. https://doi.org/10.1121/1.3132523.
Tsouvalas, A., Metrikine, A.V., 2016. Noise reduction by the application of an air-bubble curtain in offshore pile-driving. J. Sound Vib. 371 (June), 150–170. https://doi.org/10.1016/j.jsv.2016.02.025.
Tyack, P.L., Zimmer, W.M.X., Moretti, D., Southall, B.L., Claridge, D.E., Durban, J.W., Clark, C.W., D'Amico, A., DiMarzio, N., Jarvis, S., McCarthy, E., Morrissey, R., Ward, J., Boyd, I.L., 2011. Beaked whales respond to simulated and actual navy sonar. PLoS One 6. https://doi.org/10.1371/journal.pone.0017009.
Verfuß, U.K., Dähne, M., Diederichs, A., Benke, H., 2008. Applications and analytical methods for T-Pod deployment in environmental impact studies for wind farms: comparability and development of standard methods. In: Offshore Wind Farms and Marine Mammals: Impacts & Methodologies for Assessing Impacts, pp. 27–31.
Villadsgaard, A., Wahlberg, M., Tougaard, J., 2007. Echolocation signals of wild harbour porpoises, Phocoena phocoena. J. Exp. Biol. 210, 56–64. https://doi.org/10.1242/jeb.02618.
Würsig, B., Thewissen, J.G.M., Kovacs, K.M., 2018. Encyclopedia of Marine Mammals. Academic Press.
Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A., Smith, G.M., 2009. Mixed effects models and Extensions in Ecology with R. Springer, pp. 221–392.
Zuur, A.F., Leno, E.N., Walker, N.J., Saveliev, A.A., Smith, G.M., 2011. Mixed effects models and extensions in ecology with R. Public Health. https://doi.org/10.1016/B978-0-12-387667-6.00013-0.

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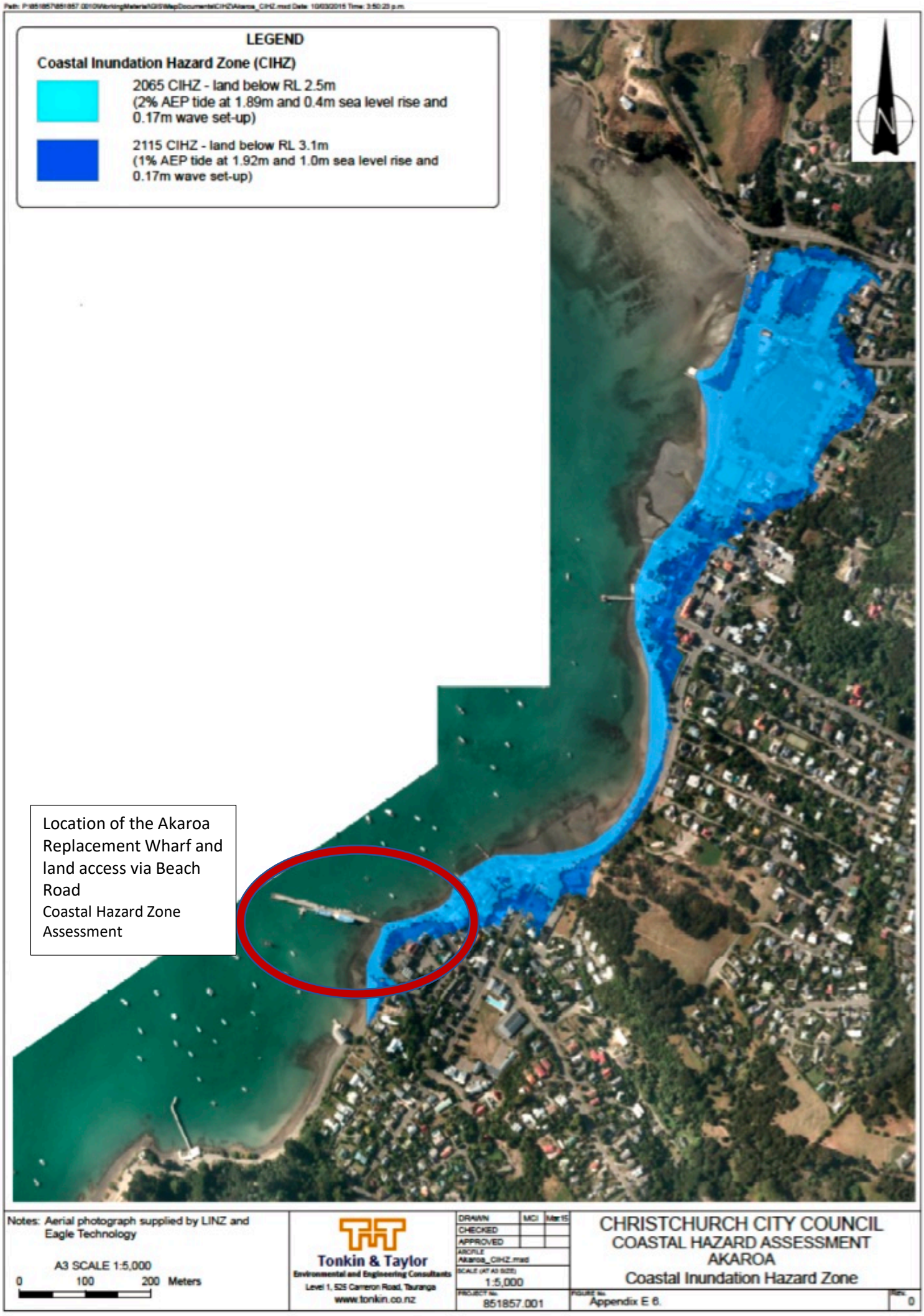

Attachment 2, Victoria Andrews, Akaroa Wharf Replacement Submission

Examples of waterfront design features

Please note that recreational use is kept separate from commercial operators

Oslo, Norway, Opera House with steps down to the water

Singapore

Niederhafen River Project

Sea Organ, Zadar

Oriental Bay, Wellington, Isthmus

Above and below: Isthmus, Auckland Ferry Terminal & waterfront redevelopment with steps
*Note that commercial operators are kept separate from the public and recreational users